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TECHNICAL EVALUATION OF THE RHS 200 FOR HIGH SPEED FERRY APPLICATIONS AND COAST GUARD MISSIONS

FINAL REPORT

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16. Abstract

A PERFORMANCE AND PASSENGER FERRY EVALUATION OF A RODRIQUEZ CANTIERE NAVALE SURFACE-PIERCING HYDROFOIL SHIP (RHS 200) WAS CONDUCTED FOR THE USCG AND UMTA. CALM AND ROUGH WATER POWERING CHARACTERISTICS OF THE 125-TON, 254 PASSENGER, DIESEL-POWERED SHIP WERE DETERMINED. THE TESTS INCLUDED INVESTIGATION OF SHIP TAKEOFF POWER, TIME, AND DISTANCE REQUIREMENTS. A WIDE SCOPE OF HULLBORNE AND FOILBORNE TURNING TRIALS WERE PERFORMED. BOLLARD PULL AND UNDERWAY TOWING CAPABILITIES WERE ASSESSED. EMERGENCY STOPPING DISTANCES WERE ALSO DETERMINED.

THE BOW WAKE OF THE SHIP WAS MEASURED, INTERIOR AND EXTERIOR SOUND LEVELS WERE RECORDED, AND SPECTRAL DEFINITION OF STRUCTURAL VIBRATIONS WERE OBTAINED. THE ROUGH WATER TRIALS PRIMARILY CONSIDERED THE EFFECT OF THE FLAP-CONTROLLED SEAKEEPING AUGMENTATION SYSTEM ON SHIP MOTIONS AND ACCELERATIONS IN STATE 3 AND STATE 5 SEAS. THE FERRY SERVICE EVALUATION INCLUDED SHIP COMPLIANCE WITH USCG APPLICABLE REQUIREMENTS AND OPERATIONAL AND ARRANGEMENT INFORMATION PERTINENT TO FERRY UTILIZATION. INDEPENDENTLY DEVELOPED CURVES OF FORM ARE INCLUDED.

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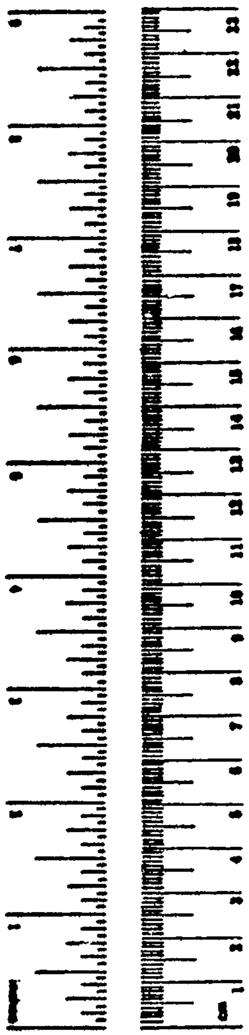
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

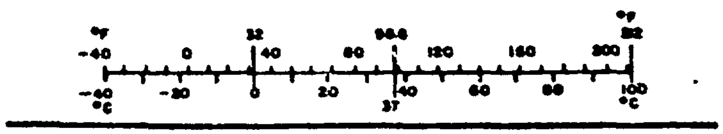


TABLE OF CONTENTS

LIST OF FIGURES vi

LIST OF TABLES viii

ABSTRACT 1

ADMINISTRATIVE INFORMATION 1

INTRODUCTION 3

SHIP CONFIGURATION AND TEST BACKGROUND 5

RHS 200 HYDROFOIL SHIP 5
TEST DEVELOPMENT AND SCOPE 15
DATA ACQUISITION AND INSTRUMENTATION 18
DATA REDUCTION 23

RHS 200 CALM WATER PERFORMANCE EVALUATION 27

CALM WATER SPEED AND POWER 27
Light and Heavy Ship Speed and Power 27
Takeoff Evaluations 39

CALM WATER TURNING 52
Spiral Turning 52
Tactical Diameters 56
Zig-Zag Maneuvers 62
Low Speed Maneuverability 71

TOWING PERFORMANCE 73
Bollard Pull 73

Underway Towing Capability 74
RHS 200 Under Tow 76

ATTENDANT CHARACTERISTICS 78
Tactical Response 78
Crash Stop Response 82
Wake Evaluation 83
Noise Measurements 84
Structural Vibrations 87

RHS 200 ROUGH WATER PERFORMANCE EVALUATION 95

TEST CONDITIONS 95
Scope of Tests 95
Sea Conditions 97
Data Analysis Notes 102

ROUGH WATER SHIP PERFORMANCE 105
Hullborne Speed and Power 105
Rough Water Takeoffs 105
Foilborne Speed and Power 108
Rough Water Turning 113

ROUGH WATER RESPONSE CHARACTERISTICS 116
Pitch and Roll Motions 116
Acceleration Amplitudes 121
Supportive Information 127

GENERAL EVALUATION 153

ADDITIONAL ENGINEERING FACTORS 153

Hotel Load 153

Watertight Integrity 153

Moment to Heel or Trim 159

OPERATIONAL PARAMETERS 159

Operations Equipment Arrangement 159

Visibility From the Deckhouse 160

Pierside, Offshore, Fog Navigation and Night Operations 160

DECK EQUIPMENT ARRANGEMENT AND OPERATION 162

Deck Equipment Arrangement 162

Anchoring 163

Boat Launching Capability 163

ENGINEERING EQUIPMENT ARRANGEMENT 163

RELIABILITY AND MAINTAINABILITY 164

Reliability 164

Observed Operational Reliability, Maintainability and Availability .. 164

ABILITY TO SUPPORT MISSIONS 167

Observed Mission Support Capability 167

Subjective Mission Support Capability 168

Subjective Seakeeping 169

Survivability 170

Interoperability and Logistics 170

Habitability 171

SECONDARY VARIABLES 172

FERRY SERVICE EVALUATION 173

PASSENGER AND BAGGAGE CAPACITY 173

PASSENGER ACCESSIBILITY 174

Wheelchairs 174

Other Considerations 175

PASSENGER COMPARTMENT MOTION 176

CRAFT AVAILABILITY 176

ACCEPTABILITY UNDER USCG REQUIREMENTS 177

General Provisions 178

Inspection and Certification 178

Construction and Arrangement 178

Watertight Subdivision 181

Stability 183

Lifesaving Equipment 184

Fire Protection Equipment 186

Operations 187

Nuclear Vessels 187

Disclosure of Safety Standards/Registry 187

Marine Engineering 188

Electrical Engineering 188

OPERATIONAL FACTORS 188

Pilothouse Visibility 188

Instrumentation and Control Layout 188

Night Operations Capability 189

PIER FACILITIES SUPPORT 189

Minimum Water Depth 189

Fenders and Camels 189

Ramps 189

Shore Connections 190

MANNING REQUIREMENTS 190

CRAFT OPERATING PARAMETERS 191

EMERGENCY OPERATING PROCEDURES 192

HOUSEKEEPING CHARACTERISTICS 192

MANEUVERABILITY 192

STOPPING CHARACTERISTICS 193

STRUT FAILURE CONDITION 193

WAKE EVALUATION 193

OPERATION AND MAINTENANCE 194

PHOTOGRAPHS 196

SUMMARY AND CONCLUSIONS 214

ACKNOWLEDGEMENTS 222

REFERENCES 223

APPENDIX A 224

LIST OF FIGURES

1 - RHS 200 Hydrofoil (SUPERJUMBO) 6

2 - RHS 200 Outboard Profile and Main Deck Plan 7

3 - RHS 200 Inboard Profile and Lower Deck Plan 8

4 - Foil System Schematic 13

5 - Data Acquisition Configuration 19

6 - Light Ship Speed and Power Performance 28

7 - Heavy Ship Speed and Power Performance 29

8 - Propulsion Fuel Consumption 33

9 - Specific Fuel Consumption 34

10 - Thrust Data Comparisons and Propulsive Efficiency 35

11 - Foilborne Height and Trim 37

12 - Effect of Ship Trim on Foilborne Speed-Power 40

13 - Single Engine Hullborne Performance 41

14 - Light Ship Minimum Power Takeoff 43

15 - Light Ship Takeoff Performance 45

16 - Light Ship Zero Flap Takeoff Performance 46

17 - Heavy Ship Takeoff Performance 47

18 - Heavy Ship Zero Flap Takeoff Performance 48

19 - Light and Heavy Ship Takeoff Comparisons 49

20 - Ship Trim During Takeoff 51

21 - Hullborne Spiral Turning at 10 and 16 Knots 54

22 - Foilborne Spiral Turning at 28 and 35 Knots 55

23 - Ship Speed During Spiral Turns 57

24 - Hullborne Tactical Diameters at Full Rudder 61

25 - 35 Knot Minimum Tactical Diameters 63

26 - Effect of Speed on Foilborne Tactical Diameter 64

27 - Tactical Diameter Turn Development 65

28 - Zig Zag Maneuver at 16 Knots With 10 Degrees of Rudder 67

29 - Zig Zag Maneuver at 16 Knots With Full Rudder 68

30 - Zig Zag Maneuver at 35 Knots With 20 Degrees of Rudder 69

31 - Zig Zag Maneuver at 35 Knots With Full Rudder 70

32 - Bollard Pull Capability 75
33 - Underway Towing Performance 77
34 - RHS 200 Under Tow 79
35 - Ship Wake Profiles 85
36 - Broadside Transmitted Sound Levels 88
37 - Structural Vibration Spectrum: Upper Cabin at CG; 16 Knots 90
38 - Structural Vibration Spectrum: Upper Cabin at CG; 35 Knots 91
39 - Structural Vibration Spectrum: FWD Lower Cabin; 35 Knots 92
40 - Structural Vibration Spectrum: AFT Lower Cabin; 35 Knots 93
41 - Rough Water Trials Matrix 96
42 - Wave Height Histograms 98
43 - Test Sea Conditions 100
44 - Hullborne Speed and Power in State 3 Seas 106
45 - Takeoff Performance in State 3 Seas 107
46 - Takeoff Performance in State 5 Head Seas 109
47 - Calm and Rough Water Takeoff Comparisons 100
48 - Foilborne Speed and Power in State 3 Seas - SAS Active 111
49 - Foilborne Speed and Power in State 5 Seas 112
50 - Foilborne Range in State 5 Seas 114
51 - Hullborne Pitch and Roll Motions in State 3 Seas 118
52 - Foilborne Rough Water Pitch Motions 119
53 - Foilborne Rough Water Roll Motions 120
54 - Lateral and Vertical Accelerations at CG 122
55 - Surge Accelerations at CG 124
56 - Pilot House Lateral and Vertical Accelerations 125
57 - Worst Case Accelerations in State 5 Seas 126
58 - Pitch Response in State 3 Head Seas 129
59 - Pitch Response in State 3 Following Seas 130
60 - Pitch Response in State 5 Head Seas 131
61 - Pitch Response in State 5 Following Seas 132
62 - Flap Motions Under Head Sea Conditions 133
63 - Flap Motions Under Following Sea Conditions 134
64 - Roll Response in State 3 Port Beam Seas 135

65 - Roll Response in State 5 Port Beam Seas 136
66 - Typical State 5 Seas Accelerometer Traces 137
67 - Pilot House Lateral Acceleration Spectra 138
68 - Pilot House Vertical Acceleration Spectra 139
69 - Pilot House Lateral Acceleration Spectra - Effect of SAS 140
70 - Pilot House Vertical Acceleration Spectra - Effect of SAS 141
71 - Hydrostatic Analysis: Draft vs. Hull Coefficient of Form 154
72 - Hydrostatic Analysis: Draft vs. Hydrostatic Variables of Form 155
73 - Floodable Length 156
74 - Intact Stability 157
75 - Pilot House Visibility From Captain's Chair 161

LIST OF TABLES

1 - SAS Control Panel; Control and Display Capability 10
2 - Engineer's Control Station: Principal Control, Alarm and Indicator Features 11
3 - RHS 200 Performance Evaluation Trials Scope 17
4 - Data Measurand Listing 21
5 - TDAS Speed and Power Relations 24
6 - RHS 200 Speed and Power Performance Summary 30
7 - Takeoff Performance Summary 52
8 - Tactical Diameter Trials Completion 56
9 - Tactical Diameter Summary 60
10 - Low Speed Maneuverability 72
11 - Zero Speed Turning Characteristics 73
12 - Underway Response Times 80
13 - Crash Stop Response 83
14 - Airborne Noise Survey Results 86
15 - Foilborne Rough Water Turning 115
16 - Rough Water Motions - Mean Amplitudes 142
17 - Rough Water Motions - Standard Deviations in Amplitude 143

18 - Rough Water Motions - Significant Amplitudes 144

19 - Rough Water Motions - One-Tenth Highest Amplitudes 145

20 - RTA Derived Rough Water Acceleration Amplitudes -
Standard Deviations 146

21 - PSD Derived Rough Water Motions Amplitudes -
Standard Deviation Values 147

22 - PSD Derived Rough Water Motion Amplitudes - Mean Values 148

23 - PSD Derived Rough Water Flap Deflections -
Standard Deviation and Mean Values 149

24 - PSD Derived Hullborne Rough Water Acceleration Amplitudes -
Standard Deviation and Mean Values 150

25 - PSD Derived Foilborne Rough Water Acceleration Amplitudes -
Standard Deviation Values 151

26 - PSD Derived Foilborne Rough Water Acceleration Amplitudes -
Mean Values 152

27 - Hydrostatic Computer Program Input (N-600 Version) 158

28 - Operating and Maintenance Cost Estimate 165

29 - Highlights of Passenger Service Reliability, Maintainability and
Availability Per Responding Company 166

ABSTRACT

A performance and passenger ferry evaluation of a Rodriquez Cantiere Navale surface-piercing hydrofoil ship, RHS 200, was conducted for the USCG and the UMTA. Calm and rough water powering characteristics of the 125 ton, 254 passenger, diesel-powered ship were determined. The tests included investigation of ship takeoff power, time and distance requirements. A wide scope of hullborne and foilborne turning trials were performed. Bollard pull and underway towing capabilities were assessed. Emergency stopping distances were also determined. The bow wake of the ship was measured, interior and exterior sound levels were recorded, and spectral definition of structural vibrations were obtained. The rough water trials primarily considered the effect of the flap-controlled Seakeeping Augmentation System on ship motions and accelerations in State 3 and State 5 seas. The ferry service evaluation included ship compliance with USCG applicable requirements and operational and arrangement information pertinent to ferry utilization. Independently developed curves of form are included.

ADMINISTRATIVE INFORMATION

The RHS 200 hydrofoil evaluation was sponsored by the United States Coast Guard under authorization USCG MIPR Z 70099-1-07080 of 26 August 1981. The work was conducted for the U.S. Coast Guard and the Urban Mass Transportation Administration (UMTA) by the David W. Taylor Naval Ship Research and Development Center's Advanced Hydrofoil Office, Code 1150. (Work Units 1-1155-300, 1-1155-400, and 1-1155-600).

The Rodriquez built RHS 200 surface-piercing hydrofoil, owned by Societa Aliscafi - SNAV S.P.A. of Messina, Italy was chartered under Charter Contract No.

N00033-82-C-30D6 negotiated by the Military Sealift Command. Installation of the test equipment began on 5 April 1982. Actual underway trials commenced on 13 April 1982 and the agreement expired on 10 May 1982.

Mr. Tom Milton and Lt. Peter Boyd, both representing the U.S. Coast Guard participated in the trials.

INTRODUCTION

The David Taylor Naval Ship Research and Development Center (DTNSRDC) was requested by the United States Coast Guard (USCG) and the Urban Mass Transportation Administration (UMTA) to evaluate a RHS 200 Hydrofoil Ship in terms of its overall calm and rough water performance and in terms of its suitability as a high speed passenger ferry.

The RHS 200 is a diesel-powered, surface-piercing, hydrofoil ship of 125 tons displacement which is being built by the Rodriquez Cantiere Navale S.P.A., Messina, Sicily. The ship is of interest because of its relatively large size and passenger capacity and the refinements which have been made to improve ride quality in a seaway. The RHS 200 is designed to carry up to 254 passengers over a range of 200 nautical miles at a cruising speed of 36 knots. The RHS 200 is fitted with a Seakeeping Augmentation System (SAS) which uses analog programmed control of hydraulic actuated flaps installed on the foil systems to reduce ship motions in rough water.

UMTA is interested in the RHS 200 because it is examining the use of high speed ferry services for cost-effective improvement of commuter access to inner city areas and for special interest routes. The USCG had identified the RHS 200 hydrofoil as one of several advanced marine vehicles which could be considered as potential replacements for the WPB class patrol craft.

The David Taylor Naval Ship Research and Development Center's Hydrofoil Special Trials Unit Detachment (DTNSRDC-HYSTUDET) developed a trials plan which responded to the technical trials needs of both the USCG and UMTA and assembled a data acquisition system to be used during the trials. DTNSRDC, through the auspices of the Military Sealift Command, arranged the lease of the prototype RHS 200, SUPERJUMBO, for the period of the trials. In April 1982, a trials team consisting of DTNSRDC, DTNSRDC-HYSTUDET, USCG and Contractor personnel were deployed to Messina, Sicily to conduct the trials. The trials were completed via 12 separate daily voyages undertaken within the on-site period of 5 April through 12 May 1982.

This report contains the results of the RHS 200 performance evaluation and the related investigations. The content and the format of the report has been selected and arranged to satisfy both USCG and UMTA performance assessment

requirements. The overall performance evaluation of the RHS 200 is presented first in the report. Sections addressing specific USCG and UMTA information requirements follow. UMTA requested passenger and trials participant questionnaires are summarized in Appendix A.

SHIP CONFIGURATION AND TEST BACKGROUND

RHS 200 HYDROFOIL SHIP

The RHS 200 SUPERJUMBO, shown in Figure 1, is designated Rodriquez hull number 192 and is the prototype of a new series of surface-piercing hydrofoil ships being developed by Rodriquez for use as high speed passenger ferries. Inboard and outboard profiles, deck plans, and other general information descriptive of the RHS 200 type hydrofoils are given in Figures 2 and 3. These figures have been developed from similar information presented in Reference (1). The overall length of the RHS 200 is 117.5 feet, and the beam of the hull is just under 23 feet. Because the surface-piercing foil systems are non-retractable, they are the controlling factors on overall beam and ship draft. Maximum width, or span, across the foils is 47.2 feet. Maximum draft is approximately 15 feet when the ship is pierside or is operating in the hullborne mode. In the foilborne mode, the ship operates with a draft of 6.8 feet. The ship was designed to a displacement of 125 tons. The displacement is 133.8 tons at the overload condition with full passenger, baggage, fuel and liquids, and crew load. A full load displacement of 123 tons is targeted for follow-on ships. The normal fuel capacity is 5.9 tons.

The hull of the RHS 200 is constructed of magnesium alloy aluminum. The framing, longitudinal, and other main hull structural components are weldments. Hull and deck platings and the interior and exterior cabin bulkheads have been assembled using aircraft style, riveted, manufacturing procedures. The ship is arranged to contain two passenger decks, a lower level machinery space, and a pilothouse. The lower deck is divided into forward and after passenger salons by the amidships machinery space. The main deck, or belvedere, passenger cabin is effectively divided in forward and after sections by access arrangements. Each of the four passenger areas provides seating for approximately 60 individuals. Two restrooms are included on each deck. The RHS 200 used in the trials included a bar installed on the aft, starboard side of the forward salon. The after end of the belvedere cabin was extended to include a baggage storage area. All of the passenger areas are well appointed, carpeted, air-conditioned, and they

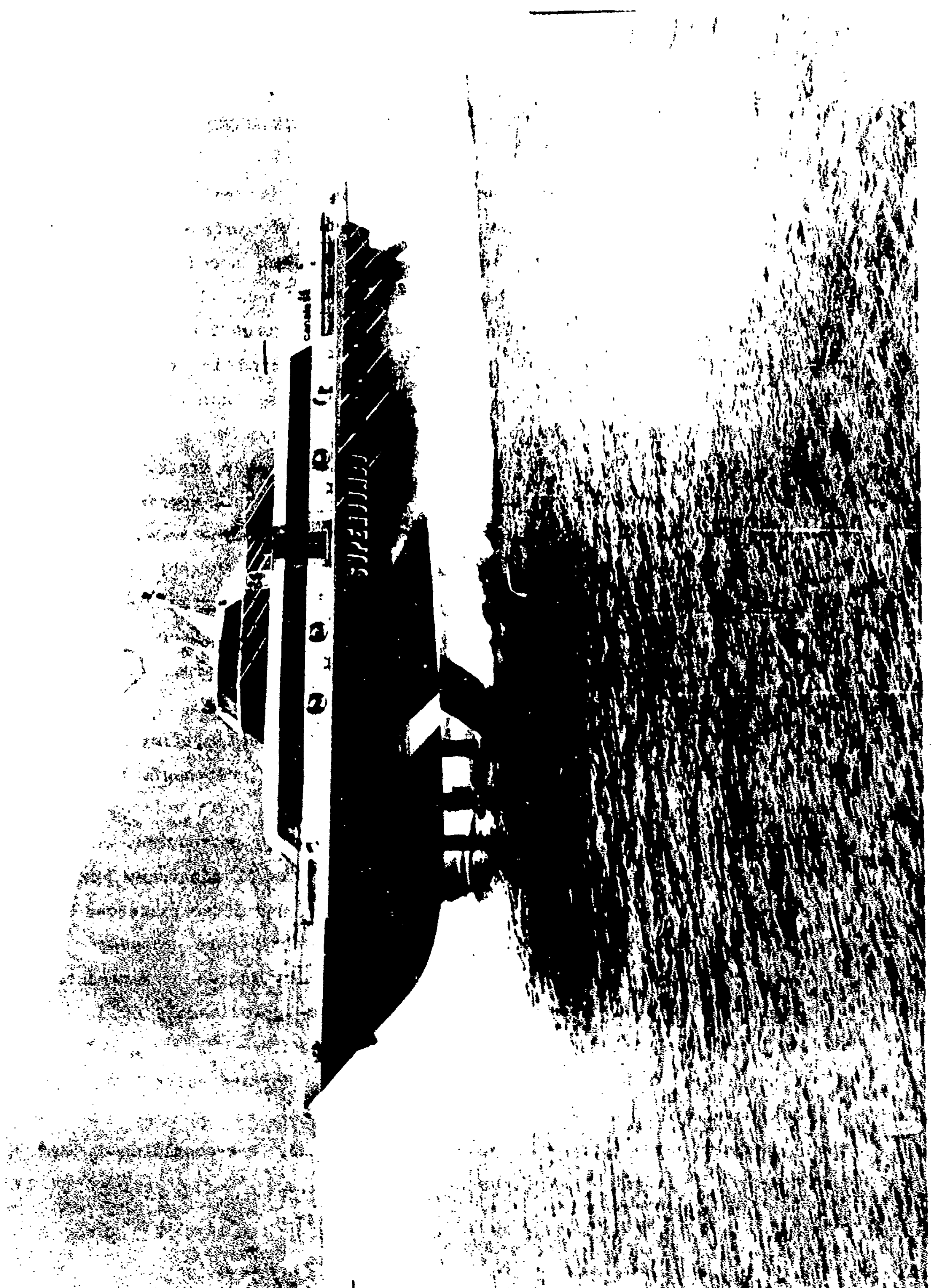
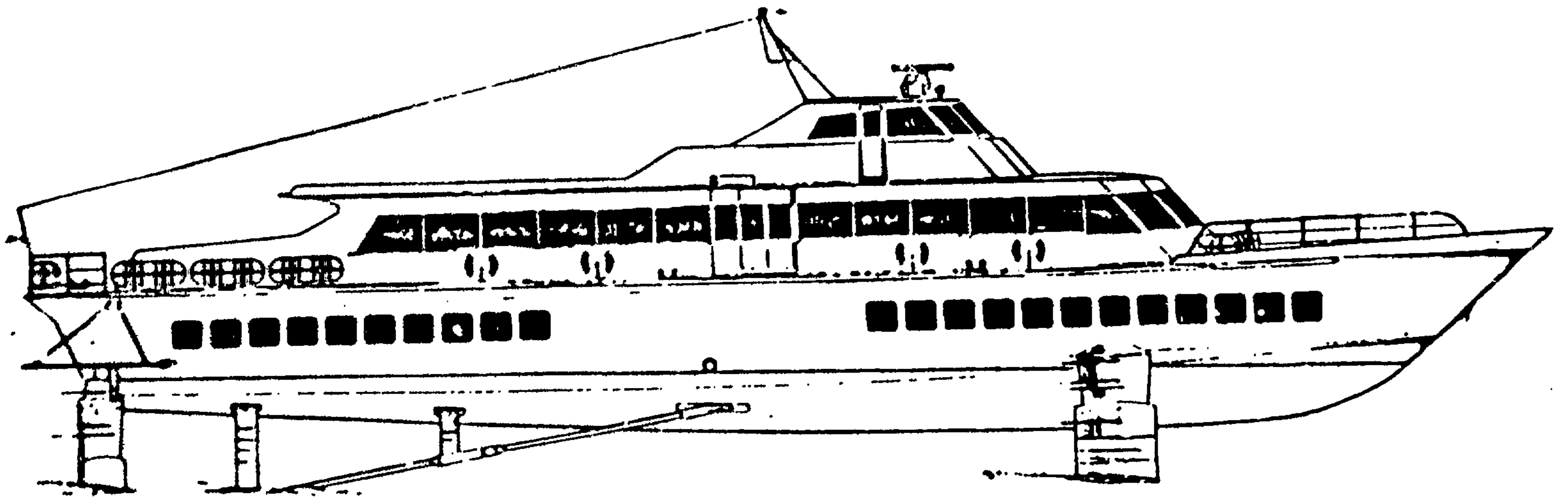
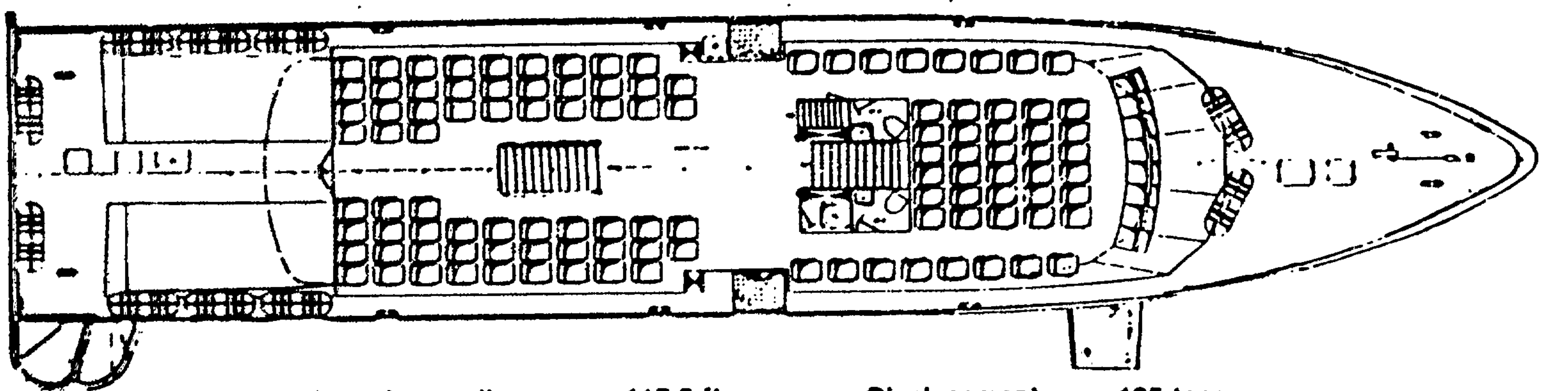


Figure 1 - RHS 200 Hydrofoil (SUPERJUMBO)

RHS 200 PERFORMANCE EVALUATION · APRIL 1982





Length overall	117.5 ft.	Displacement	125 tons
Molded breadth	23.0 ft.	Power plant	2 x 2600 HPM
Width across foils	47.2 ft.	Cruising speed	36 knots
Draft, waterborne	14.9 ft.	Cruising range	200 nm
Draft, foilborne	6.8 ft.	Passengers	254

Figure 2 - RHS 200 Outboard Profile and Main Deck Plan

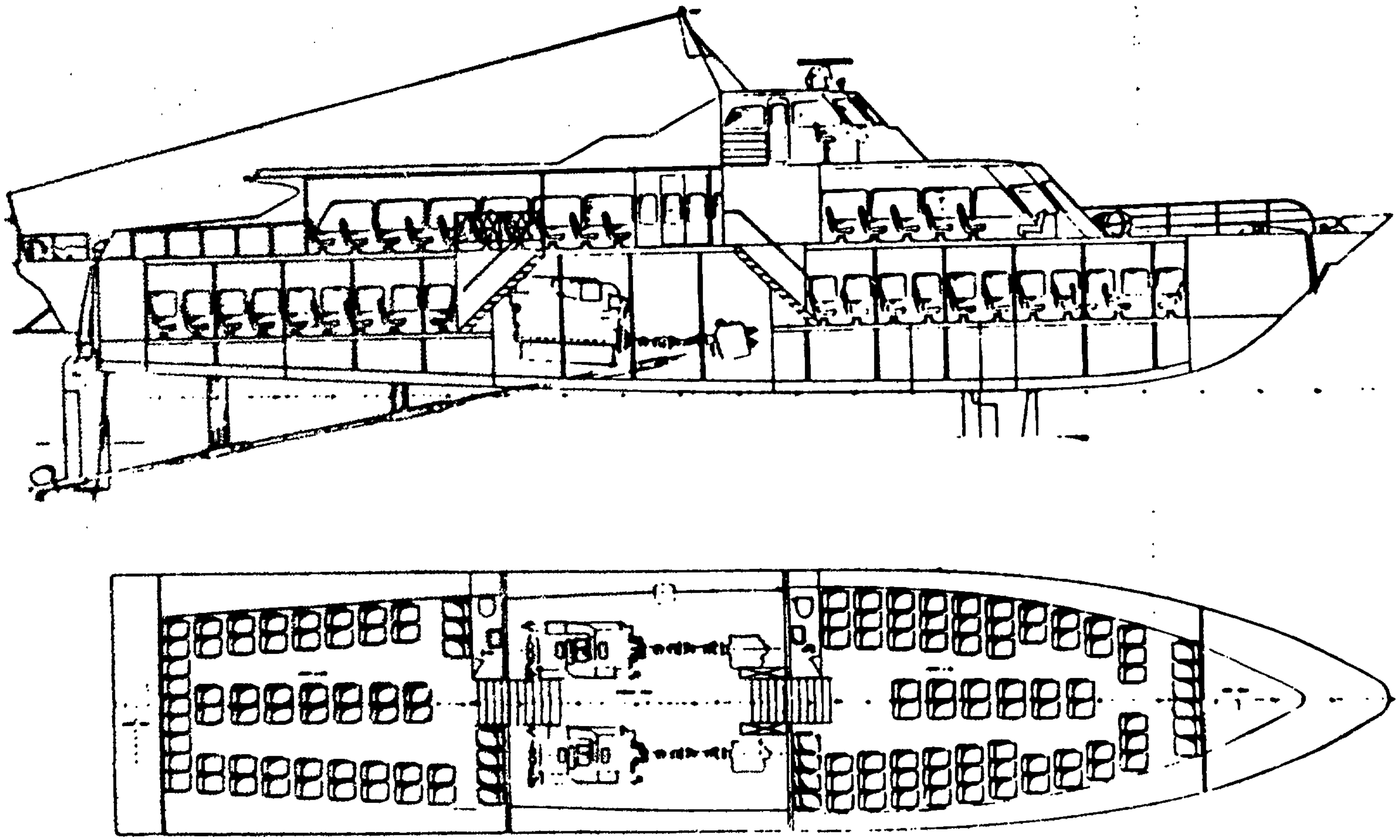


Figure 3 - RHS 200 Inboard Profile and Lower Deck Plan

provide good exterior viewing. Aircraft style, non-reclining, seating is used throughout. Closed-circuit television and audio entertainment systems are also installed.

Weather deck areas are normally not for passenger use and are limited to fore and quarter decks and narrow weather passages down each side of the belvedere cabin. The foredeck is used for anchor equipment and as a ship mooring station. The quarter deck is also a ship handling station and is used for crew and passenger boarding when the ship is tied-up, stern-to, in Mediterranean style mooring. In the rapid turnaround, ferry service environment, passenger boarding can be through amidship accesses on either side of the belvedere cabin. In these instances the ship is brought alongside, pierside ramps are extended, and boarding commences.

During operation, all ship control is exercised from the pilothouse. The bridge console is arranged for three manned stations.* The Captain occupies the center position and has direct control of the helm and the SAS Control and Status Panel. The principal features of the SAS control panel are listed in Table 1. This information effectively highlights the extent to which the operator can exercise control of the SAS. The navigational radar is installed on the left-hand side of the bridge console. This station is manned by a crew member who operates the radar when required. The RHS 200 is equipped for open ocean navigation and communication. Loran C equipment is also installed.

The engineers station, situated on the right side of the bridge console, is the third manned station included within the pilothouse. The engine room is designed as an unmanned space. Therefore, all propulsion and auxiliary system control, indication and alarm functions are incorporated into the engineering section of the bridge console. The principal features of this installation are summarized in Table 2. The station includes panel assemblies which were made by the manufacturers of different systems used on the ship and by Rodriquez,* therefore, there is some duplication of installed indicator and alarm functions. The duplications have been omitted from Table 2.

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*Refer to photographs at the end of the Ferry Evaluation Section at pages 201-205

TABLE 1 - SAS CONTROL PANEL CONTROL AND DISPLAY CAPABILITY

- SAS Mode Selection: Self Test, Manual, Takeoff, Automatic
- Analog Display of Ship Pitch and Roll Angles - 2 Gages
- Analog Display of Flap Positions - 4 Gages
- Potentiometer Control of Pitch, Roll and Heave Trim
- Potentiometer Control of Pitch, Roll and Heave Channel Gains
- Selective Self Test of Pitch, Roll and Heave Channels
- Engage, Disengage, Forward Rudder Control
- Gyroscope Power and Status Indication
- Self-Test Voltage Readout
- System Power and Status Indication

The main equipment installed in the machinery space include the propulsion diesels, reduction gearboxes, diesel generator units, and a power distribution switchboard. The load capability of the generators is reviewed under the hotel loads discussion of the General Evaluation Section. A single generator is used for normal operating loads. The second unit is brought on-line when the air-conditioning load is applied. The power distribution panel is located in the pilothouse for navigation light circuits. Fire-fighting equipment consists of fixed CO_2 self-contained automatic systems for power plant and fuel tank spaces, and portable extinguishers for cabins and holds.

RHS 200 propulsion is supplied by two MTU 16V652-TB81 diesel engines which are rated at 2600 horsepower each. The engines drive forward through reversing reduction gearboxes which provide 1:1.718 reduction between the engine and the propeller shafts. Maximum engine output speed is 1460 RPM which results in a maximum propeller shaft speed of 850 RPM. Angled shafts are used to connect the gearboxes with the propellers which are close-mounted immediately aft of the rear foil. Special hardware known as distance pieces, instrumented to measure propeller shaft torque, thrust and RPM, were installed in both propeller shafts at the output side of the reduction gearboxes.

TABLE 2 - ENGINEER'S CONTROL STATION: PRINCIPAL CONTROL, ALARM AND INDICATOR FEATURES

- Combined Ahead, Astern Propeller Pitch and Engine Throttle Control
- MTU Engine Cylinder Temperature Alarm and Selectable Digital Indication
- MTU Engine Status Alarm and Selectable Digital Indication for:

Charging Air Pressure	Sea Water Pressure
Starting Air Pressure	Cooling Water Temperature
Cooling Water Pressure	Piston Cooling Oil Pressure
Engine Oil Pressure	Engine Oil Pressure
Gear Oil Temperature	Gear Oil Pressure At Filter
Gear Control Oil Pressure	

- MTU Analog Indicators for:

Fuel Rack Position	Engine Percent Load
Engine Speed	Propeller Shaft Speed

- Engine Start, Stop and Emergency Stop Control
- Propulsion System Alarm and Indication for:

Clutch Position Ahead	Engine Speed Sensor Failure
Clutch Position Astern	Shaft Speed Sensor Failure
Disengaged Clutch	Fuel Oil Pressure Low
Overspeed	Starting Repetition

- Analog Display of Reduction Gear Temperatures
- Propeller Pitch Control and Status Including:

Analog Pitch Display	Fine Pitch Adjustment
Load Control On/Off	Constant RPM On/Off
Back Up Control On/Off	Normal/Takeoff Selection
Ahead Control	Astern Control

- Fire Alarm System Status and Control Panel
- Electrical Distribution System Control and Status Panel
- Cabin Environmental System Control Panel

At the time of the trials, three bladed, supercavitating, controllable-pitch (CP), propellers were installed on the ship. They were manufactured by Karlstad Mechanical Werkstadt (KaMeWa) of Karlstad, Sweden. The CP installation also included load control units which provided programmed interfacing of propeller pitch control to the load characteristics of the engines.

Except for the selection of the MTU 16V652-TB81 engines and the use of CP propellers, this propulsion arrangement is typical of that used on all Rodriquez hydrofoil ships. At the time of the trials, Rodriquez representatives expressed concern with the power available from the MTU engines and the relatively high, 670°C, exhaust stack temperatures at which they operated. Alternative engine selections were under consideration. However, these problems have been corrected. The engines for the next RHS 200, the YBN 209, have undergone successful acceptance tests. The exhaust gas temperature was decreased from 670°C to an average of 550°C. Rodriquez also believed that the CP propellers were operating at efficiencies which were much lower than that available from the fixed-pitch, subcavitating propellers which they normally use. Fixed-pitch propellers, designed to fit the existing CP shafts, were on order and were planned for installation and evaluation in the fall of 1982. These comments are somewhat at odds with information given in Reference (2) which notes that the CP propeller installation is satisfactory. It is also noted in the reference that the use of supercavitating propellers resulted in prolonged propeller life.

The foil system schematic included in Figure 4 has been adapted from Reference (1) for discussion purposes. The forward and aft foil systems shown in central portions of the figure only include those system components which either generate lift or are used for directional control. The supplementary sketches in the figure, which include outlines of hull cross sections, are intended to provide typical definition of the entire foil system, including those elements whose main function is structural support. The components of the foils systems are largely hollow weldments which have been manufactured out of nickel-copper alloy steel. The welded assemblies are fixed to structural hard points at the hull using bolt-up attachments.

The trailing edge flaps shown in Figure 4, which are installed on the RHS 200 foil systems, are not required for normal operation of the ship. Basically,

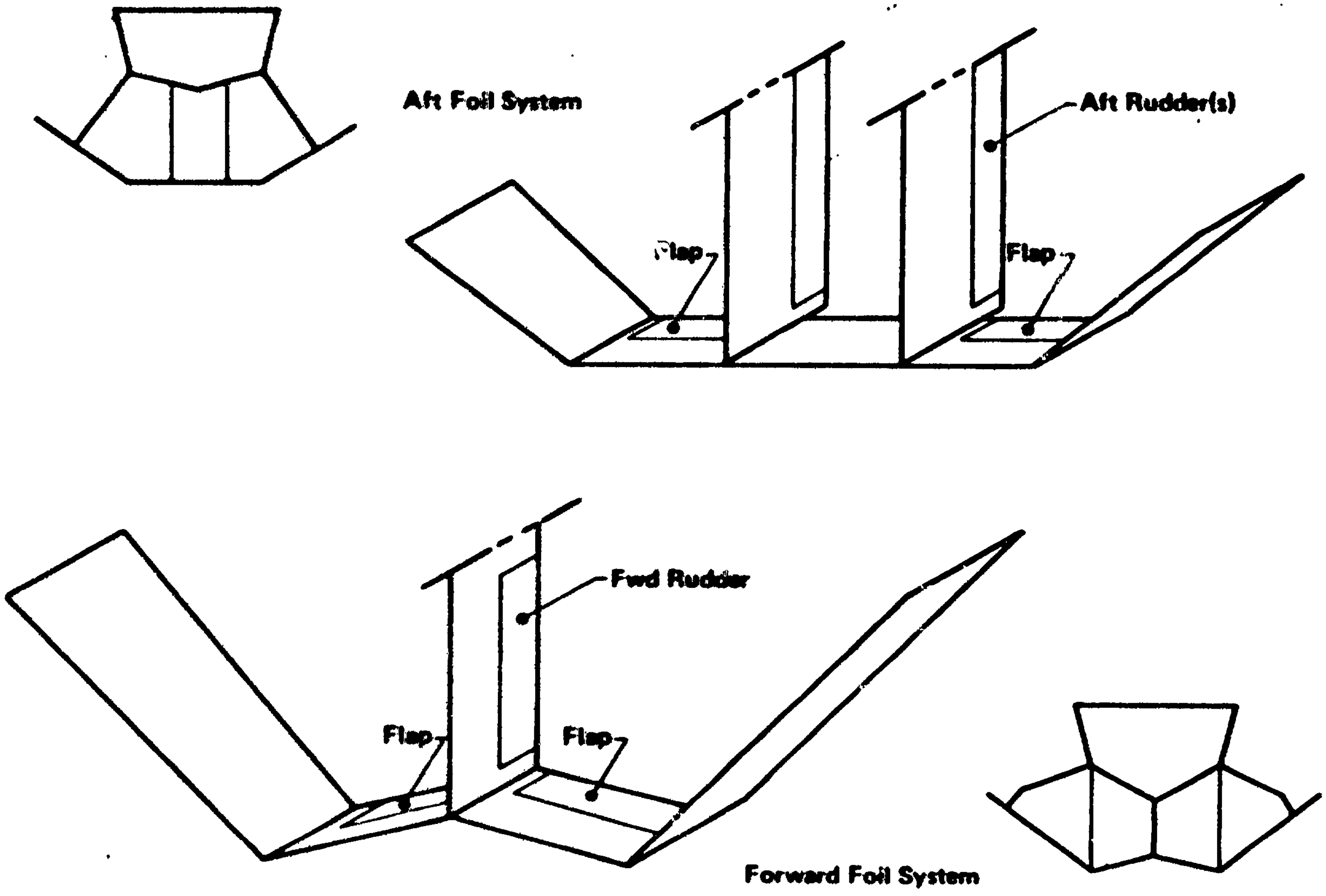

Figure 4 - Foil System Schematic

the lift forces developed by a conventional surface-piercing hydrofoil system are functions of the submerged area of the foils and the square of ship speed. As ship speed is increased in the hullborne mode, increasing values of lift are generated by the essentially fully submerged foil system. Takeoff occurs at a speed where the lift forces are sufficient to support the weight of the ship. As the hull clears the water surface, lift-producing elements of the foil system are also exposed and an inherent trade-off between ship speed and remaining submerged foil area is initiated. Flying height is maintained without the use of height sensors, automatic control systems, or similar equipment. A surface-piercing foil system is inherently stable in all modes of foilborne operation, including calm and rough water conditions and turning maneuvers.

Any hydrofoil system will react to surface disturbances of the sea. The reaction is typically more pronounced in the case of a surface-piercing system because of the interfacing of lifting surfaces with the surface of the sea. Rodriquez engineers, in conjunction with the Hamilton Standard Division of United Aircraft, have developed the SAS as a means for improving the rough water ride qualities of their larger series ships. The SAS uses a gyroscope and accelerometer sensor package, mounted in the machinery space near the center of gravity of the ship, to sense ship motions. The motion signals are input to an analog computer which is integral with the SAS control panel installed on the bridge. The computer uses this, and flap position feedback information, to exercise the electro-hydraulic flap control required to minimize ship motions in a seaway. Each flap is driven by a desparate hydraulic actuator. Position transducers, mounted on the actuators are used to sense flap position. Hydraulic power is supplied by electrically driven pumps installed in the machinery space. The W-shaped transverse section of the forward foil system, shown in Figure 4, has been adopted to allow the forward flaps to exercise increased roll control authority.

As outlined in Table 1 several modes of SAS operation are available. In the Self Test mode the analog computer executes a diagnostic evaluation that is intended to confirm full operational status of the system. In the Manual mode the operator can use the flaps to trim the ship in roll, pitch, or heave. In the Takeoff mode the forward flaps are deflected down to a position of approximately 12 degrees. This increase in forward foil lift causes the ship to increase trim

which results in increased lift from the working elements of both foil systems. The Takeoff mode is manually disengaged when the takeoff is completed. The SAS Automatic mode provides full computer-controlled dynamic positioning of the flaps in response to rough water ship motions. The operator can still exercise roll, pitch and heave trim control with the SAS in the Automatic mode. The operator can also exercise limited control of the rate of response of the SAS system by the selection of low, medium, or high gain settings in the roll, pitch and heave channels.

Directional control of the RHS 200 is provided by the dual aft and single forward trailing edge rudders shown in Figure 4. The aft rudders are controlled by a common actuator which is directly driven from the helm. These rudders can be deflected nominally 30 degrees in either direction. An aft rudder position signal is taken from a transducer installed on the actuator and is input to the SAS analog computer for control of the forward rudder. The forward rudder is not deflected until the aft rudders are deflected 10 degrees and its deflection rate per unit of helm position is programmed to be one-half that of the aft rudders. These procedures have been adopted to provide a more physically comfortable turn during foilborne operation. The SAS control panel includes a switch which allows the operator to disengage the forward rudder if desired. There is no other SAS input or control of ship turning. Flap-induced rolling of the ship into a turn cannot be used to improve the turning characteristics of a surfacing-piercing foil system.

TEST DEVELOPMENT AND SCOPE

The evaluation of the RHS 200 was performed under the joint sponsorship of the USCG and UMTA. The USCG interest in the RHS 200 was based on the ship's potential as a replacement for the WPB class patrol boat, while the UMTA interest rested in the design role of the ship as a high speed passenger ferry. Test requirements, which differed substantially in many areas but were largely common in the area of ship performance evaluation, were developed by each agency. Full definition of USCG test needs are defined in Reference (3) while UMTA data requirements are given in Reference (4). DTNSRDC-HYSTUDET was assigned responsibility for the design, conduct and documentation of a test series which would

explore the ship performance test requirements which were common to both sponsors. The resulting trials agenda, Reference (5), was prepared and used for the conduct of the tests.

A summary of the test activities included in the trials agenda is given in Table 3. The open and closed symbols in the table provide broad indication of test completion. Details of the procedures used in the conduct of the tests and the results achieved are given in the Calm and Rough Water Performance Evaluation Section of this report; the two major areas of interest. As is indicated by the closed symbols in Table 3, it was possible to complete a major portion of the calm water tests. All of the specific test events defined in the agenda were not performed. The agenda was written without full knowledge of the test variables which could be addressed with the RHS 200, therefore, it contained a limited number of test conditions which either could not be configured or could not be performed. For example, the agenda called for the use of three weight conditions, light and heavy ship and an overload condition, in the calm water speed and power tests. It was determined on-site that light and heavy ship test conditions of 110 and 135 tons would adequately cover all the available weight-related options. These weight variations were only considered in the conduct of the calm water hullborne and foilborne speed and power trials and the takeoff trials. All of the other trials, both calm and rough water, were performed at the heavy ship condition.

The calm water turning trials were addressed almost in their entirety. The only significant deletion was the elimination of astern spiral turns. These tests could not be performed due to a total lack of rudder effectiveness while backing down. It was possible to include test evaluation of turning capability at zero speed of advance in the trials. A wide test selection of tactical diameters and zig-zag, or debris avoidance, maneuvering tests were completed. The stopping characteristics of the ship were adequately defined and some definitive wake measurements made. Actual demonstrations of tactical response times could not be made because of harbor limitations and because of the potential for damage to the engines in the case of a "Cold Iron" situation. The time required to execute these operations were reviewed with the Captain and Chief Engineer of the RHS 200. Essentially all of the towing trials were completed.

TABLE 3 - RHS 200 PERFORMANCE EVALUATION TRIALS SCOPE

CALM WATER SPEED-POWER	
Speed Log Calibration	●
Hullborne Speed-Power	●
Calm Water Takeoff Trials	●
Foilborne Speed-Power & Trim	●
CALM WATER TURNING	
Spiral Turning	●
Debris Avoidance Maneuvers	●
Low Speed Maneuverability	●
Tactical Diameters	●
RESPONSE CHARACTERISTICS	
Stopping Characteristics	●
Tactical Response Time	●
Wake Evaluation	●
TOWING CHARACTERISTICS	
Bollard Pull Tests	●
Towing Capability	●
RHS 200 Characteristics Under Tow	●
ROUGH WATER TRIALS	
Hullborne Matrix Trials	●
R/W Takeoffs and Landings	●
Foilborne Matrix Trials	●
R/W Spiral Turning	o
R/W Debris Avoidance	o
Slamming	o
Seakindliness	o
Anchoring	o
PHOTOGRAPHIC COVERAGE	●
ACOUSTIC & VIBRATION SURVEYS	●

Legend: o not completed ● completed

The rough water trials were limited to two days of testing. On 8 May 1982 low State 5 sea conditions were encountered and it was possible to conduct foilborne matrix trials and some limited takeoff trials in that sea. The sea was at a high 3 to lower 4 conditions on the following day. It was possible to conduct hullborne and foilborne matrix trials, a fuller complement of takeoffs trials and some limited seakindliness, i.e., low speed turning, trials at that time.

Comprehensive motion picture and 35 mm slide covergae of the RHS 200, both dockside and underway, was obtained through the services as a USN Combat Photographic Team who were deployed from Siganella Naval Air Station for two days of trials support. All of the still film which was exposed was delivered to USCG representatives at the time of test. The motion picture coverage has been processed and edited by DTNSRDC and will be delivered to the USCG separate from this report.

Broadband acoustic and structural vibration data were taken on board the RHS 200 during various underway conditions. Rodriquez supplied the DTNSRDC Test Team with spectral representation of the airborne noise signature of the RHS 200 under flyby conditions. Spectural analysis of structural vibrations at a number of locations throughout the ship while operating at different speeds were also supplied.

DATA ACQUISITION AND INSTRUMENTATION

A portable data acquisition system was assembled by DTNSRDC-HYSTU and was installed on the RHS 200 for use as the primary means of data acquisition during the trials. A schematic diagram of the system is given in Figure 5. Brief descriptions of the major elements are as follows:

Power Conversion Module. Converted the 115 volt, 50 Hz ship's power to the various types of power required for the system components.

Sensor Package. An instrument platform installed near the CG of the ship containing two vertical gyros to measure pitch and roll angles; three rate gyros to measure pitch, roll, and yaw rates, and three accelerometers to measure lateral, vertical and surge accelerations at the package location.

Wave Height Instrumentation. A system consisting of a radar altimeter antenna package which was mounted on the bulwark at the bow and an electronics assembly

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

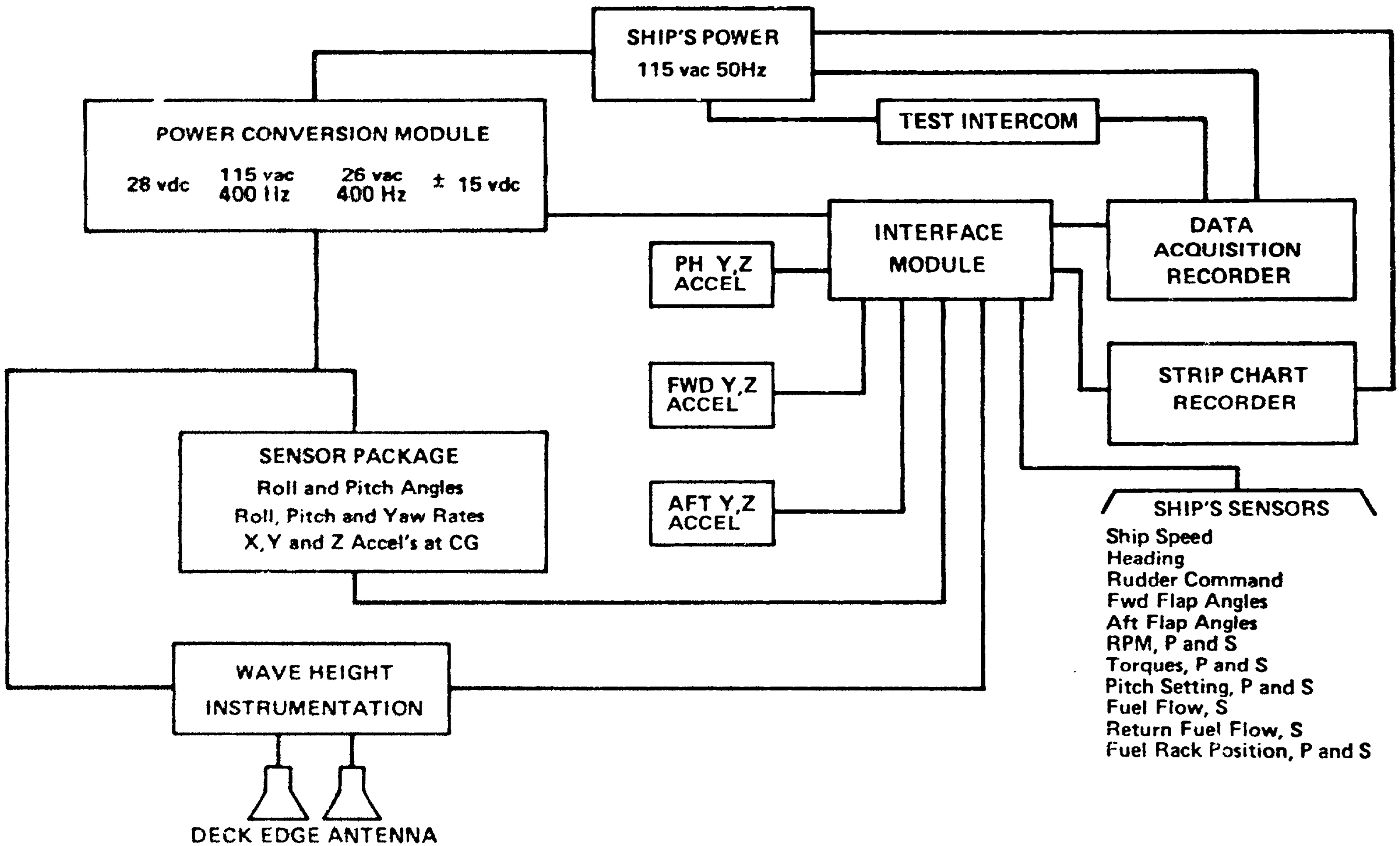

Figure 5 - Data Acquisition Configuration

which was mounted on the foredeck at the bow. The electronic assembly housed the altimeter electronics and a self-contained inertial system. Two outputs, ship's height at the bow and wave height, were generated by the wave height instrumentation.

Remote Accelerometer Packages. Three, two-axis, accelerometer packages were used to measure vertical and lateral accelerations in the lower forward and the upper after passenger cabins and in the pilothouse.

Model DS-620 Flight Recorder. A self-contained, digital, data acquisition system which was programmed to record the 38 separate data channels monitored during the trials, IRIG C time code, and the voice track from the intercom system. Cassette tapes are used for data recording. The unit has real time capability to output analog signals for any 12 of the data channels at a time. This capability was used to selectively monitor up to 8 data channels on the strip chart recorder and insure that data acquisition was functioning satisfactory during the trials. The time code generated within the flight recorder was used for time control of all tests.

Strip Chart Recorder. The 8-channel strip chart recorder was used to provide real time display of selected data parameters throughout the tests for control purposes. The unit was also used to provide post-test review of data tape contents and to provide on-site preliminary, data analysis.

Interface Module. The major functions of this unit was to provide an interface between the elements of the DTNSRDC-HYSTUDET data acquisition system, a point of input for the signals obtained from ship's instrumentation, and test point monitoring of all signals being input to the flight recorder.

Test Intercom. A 4 station intercom system used for test control communications and to provide voice annotation of the data tapes.

A summary listing of the 36 data channels measured and recorded during the trials is given in Table 4. The H, S, and R source notations included in the table indicate whether the measurands were developed within the DTNSRDC-HYSTUDET system, taken from normal ship's instrumentation, or were specifically installed for test purposes by Rodriquez, respectively.

TABLE 4 - DATA MEASURAND LISTING

SUBJECT	SOURCE
Ship Speed	S
Sine and Cosine Values of Ship Heading	R
Pitch and Roll Angles	H
Pitch, Roll and Yaw Angle Rates	H
Height at Bow and Wave Height	H
Aft Rudder Position	S
Port and Stbd Forward and Aft Flap Positions	S
Port and Stbd Propeller Shaft RPM, Torque and Thrust	R
Port and Stbd Propeller Pitch Settings	S
Stbd Engine Supply and Return Fuel Flows	R
Port and Stbd Engine Fuel Rack Settings	S
Surge Acceleration at Center of Gravity	H
Vertical and Lateral Accelerations at the:	
Forward Lower Cabin	H
Pilot House	H
Center of Gravity	H
Aft Upper Cabin	H

All of the measurands which were developed by the DTNSRDC-HYSTUDET instrumentation laboratory were calibrated during final checkout and assembly of the system. The analog displays installed on the ship were used for on-site calibration of most of the measurands which were taken from ship's instrumentation. This expedient was necessary since the ship could not be drydocked for full end-to-end calibration of the aft rudder, the flaps, and the propeller pitch settings. The fuel rack position signal was calibrated to the engine racks. Voltage calibrations, supplied by Rodriquez, were used to calibrate the heading, the speed and power related, and the fuel flow data channels.

The measurement of RHS 200 speed was accomplished using ship's instrumentation consisting of a total head tube installed on the forward foil system. The tube was plumbed to a pressure transducer installed within the hull near the displacement waterline. Speed log calibration tests were used to determine the voltage output of the transducer as a function of ship speed. The calibration runs were performed over a 1.15 nautical mile measured course which was previously established to the north of Messina harbor. A minimum of 3 runs over the course were made at each of 4 hullborne and 4 foilborne speeds. The usual operational and arithmetic procedures, detailed in Reference (4), were used to average out the relatively minor effects of tide present during the calibration. Separate calibration curves were prepared for hullborne and for foilborne, i.e., below or above 20 knots respectively, application. This approach was adopted to isolate the effect of varying ship height on total pressure at the transducer. The change in static head implied by the 8.2 feet change in draft listed in Figure 2 is equal to a 4 knot correction at 20 knots, and a 2.5 knot correction at 36 knots.

The propeller shaft RPM, thrust and torque data was measured at instrumented shaft distance pieces which were installed at the output side of the reduction gearboxes. Radio-telemetry was used for data transmittal. The transmitting equipment was not installed until after the trials had been initiated. It was also necessary to de-power the telemetry equipment whenever possible to extend the operational life of the batteries. As a result, ship powering data were not obtained during most of the calm water turning trials.

The remainder of the instrumentation system was fully operational throughout the test series. An early failure of the roll and pitch gyroscope stabilized vertical accelerometer used in the wave height inertial package required replacement of the unit. This resulted in some scaling difficulty as is discussed in the section on Sea Conditions. During data analysis, questions arose regarding the accuracy of some of the other data channels. These cases are reviewed in the following discussion.

DATA REDUCTION

The calm water data presented in this report was processed through several stages in the data reduction effort. The 12 channel analog output playback capability of the Model 620 Flight Recorder was used to input raw data voltages into a digital computer controlled, Test Data Acquisition System (TDAS) at contractor facilities. Due to the 12 channel limitation, repetitive playbacks were usually required to retrieve all data of interest for particular test series. The data calibrations were used to convert voltage values to engineering units as part of the TDAS analog to digital input process. The TDAS system was then used to process mean and standard deviation values for specific data channels over specific time intervals. The channels selected and the time intervals specified were dependent on the nature of the data being reduced and the manner in which the trials were performed. For example, in the case of the speed and power and the spiral turning tests, steady state test conditions were held for a definite period of time. In these and similar cases, a TDAS data interval of typically 20 or 30 seconds were used. The takeoff, tactical diameter, and zig-zag maneuver tests were more transitory in nature. In these instances the TDAS was programmed to provide mean and standard deviation data over one second intervals. A TDAS processing rate of 12 samples per second was used in all cases.

In many instances the test data did not require processing beyond the scaled conversion from signal voltages to engineering units and the averaging of the results. In the case of speed and power data the TDAS was programmed to convert from metric to English units and to perform the routine power, range, etc., calculations. The relations used are listed for reference purposes in Table 5.

An extensive review of the test data was made at this phase of the reduction effort. It was apparent that inconsistencies were present in the ship heading, yaw rate, port propeller torque and pitch setting, and the propeller thrust data which was obtained. On various occasions the port propeller data yielded higher torques and lower thrusts while at lower pitch than the starboard propeller when both units were at essentially equal rotational speeds. On other instances, port propeller performance was almost identical with the starboard except for a continuing pitch setting discrepancy. A decision was made to base

TABLE 5 - TDAS SPEED AND POWER RELATIONS

Torque, ft-lbs	= 0.7376(Torque, Newton-meters)
Thrust, lbs	= 0.2248(Thrust, Newtons)
Engine HP	= RPM(Torque, ft-lbs)/(.98)(5252)
Total Power or Thrust	= Sum of Port and Stbd Values
Thrust HP	= (Thrust,lbs)(Speed,knots)/(325.6)
Propulsive Efficiency, Percent	= (Thrust HP(Cos15°)/(Engine HP)100
Combined Propulsive Efficiency	= Average of Port and Stbd Values
Stbd Fuel Flow, GPH	= (Stbd Total gpm - Stbd Return gpm)60
Stbd Indicated SFC, Lbs Fuel/SHP-Hr	= (Stbd Fuel Flow, lbs/hr)/(Stbd Engine HP)
Range Factor, Naut. Mi./Ton Fuel	= (Speed, kts)(2240)/(2)(S Fuel Flow, Lbs/Hr)
Range, Naut. Mi.	= (Range Factor)(6)(.9842)

all powering data on the torque and thrust measured on the starboard shaft and to use the square of the ratio of port and starboard rpm values to estimate port propeller loads. Comparisons were made of ship powering estimates generated using this "adjusted data" and that obtained when the two torquemeters were in agreement. Since the differences between the two estimates were insignificant, it was decided to use this expedient in the preparation of all powering data included in the report. This approach could not be used with the data obtained during the towing trials because the starboard torquemeter was inoperative at that time. All of the tow trials powering data were based on port torquemeter results.

Propeller pitch setting was not viewed as a significant, independent variable in the reduction and analysis of the trials results. Little effort was

expended in determining the source of port to starboard differences or in attempting to modify the data through the application of correction factors. Of more importance to this study was the fact that questions regarding the accuracy of both the port and starboard thrustmeters were never satisfactorily resolved. A discussion of problems found in the thrust data, and the presentation of some of the typical data, is included in the Light and Heavy Ship Speed and Power Section.

The early analysis of TDAS calm water spiral turning data indicated that the ship was turning to starboard at a higher rate than to port. This offset could not be substantiated by rates of change in heading information obtained during the tactical diameter tests of in the zig-zag maneuvers. The time required to complete each 90 degree quadrant of the 540 degree tactical diameter exercises was accurately measured using the bridge compass. Rates of change in heading for the tactical diameters were also evaluated, when possible, using the sine and cosine of heading values. The yaw rates determined by these two sets of data were in agreement. Similar agreement was found in comparable, but less strenuous, investigation of heading changes during the zig-zag tests. It was concluded that an error of approximately 0.5 degrees per second was present in the output from the yaw rate gyroscope. The gyroscope was re-calibrated twice after the test by two separate agencies. The results of all available calibrations were identical and did not include the offset. The source of the error was never identified. It is postulated that it may have been due to the influence of structural vibrations on the gyroscope. The sensor package was mounted to the main deck immediately over the machinery space in an attempt to locate the package as close to the center of gravity of the ship as possible.

Averaging procedures were used to define a yaw rate correction factor from the timed 90 degree changes in heading of the tactical diameter trials. A correction of minus 0.518 degrees/second was applied to most of the turning data within this report. The tactical diameter data were the only exception. In these cases the times for the 90 degree quadrant changes were used to determine separate correction factors for each tactical diameter exercise.

The sine value of heading measurand was inoperative through a large portion of the trials. The output of both the sine and cosine functions became increasing erratic whenever the -1.0 or 1.0 values were approached. As indicated above, it was possible to use the more stable values of these functions to aid in the definition of the yaw rate discrepancy. Once the yaw rate correction factor was established, there was little additional need for data system definition of ship heading, therefore, more accurate resolution of these measurands was not pursued.

A third stage of calm water data reduction was entered after completion of the review of the TDAS processed data. This effort entailed the use of a desk top computer to investigate and to correct data as necessary in consideration of the previously noted discrepancies. The same computer was used to provide the integration required to develop time and distance type data relationships. Preliminary plotting of all test data was then used as a means to select results which were most representative of the ship's performance. The information included in this report is the result of this selection.

The rough water powering data were reduced in a manner which paralleled that used for the calm water data. Several 20 or 30 second data samples were taken along each segment of each matrix trial. Average data for these intervals were then processed as described in the above discussions. All of the remaining rough water data reduction and analysis differed substantially from those used in the case of the calm water data. The rough water sea state, ship motion, and acceleration data reduction procedures are presented in more immediate context with the data in the Data Analysis Notes Section.

RHS 200 CALM WATER PERFORMANCE EVALUATION

CALM WATER SPEED AND POWER

Light and Heavy Ship Speed and Power

Hullborne and foilborne speed and powering characteristics of the RHS 200 were evaluated under light and heavy ship weight conditions. Ship weight was estimated to be between 109 to 111 tons in the light ship configuration and 132 to 136 tons in the heavy ship condition. The individual weight ranges reflect fuel loads on board during the trials.

The trials were performed by establishing steady state operation at desired speed and recording data over an interval of at least 1 minute. The hullborne tests considered a speed range of 8 to 16 knots in 2 knot increments and a maximum hullborne speed condition. The maximum hullborne speed condition was inappropriate for this ship with a surface-piercing foil system. The ship simply takes off in the 18 to 20 knot regime. The possible use of SAS negative flap commands to hold the ship down at higher hullborne speeds was not considered. A speed range of 20 to 36 knots in 4 knot increments was attempted in the foilborne tests.

Speed and powering and range characteristics for the RHS 200 in the light and heavy ship configurations are given in Figures 6 and 7 respectively. Specific numerical comparison of the two cases can be found in Table 6. The tabular information has been taken from the faired curves within the figures. Under normal combined propeller pitch and throttle control a ship speed of approximately 7 knots results with the diesel engines at idle, i.e., 780 rpm. Lower speeds can be realized with manual reduction of propeller pitch. The fairing of the curves within the figures implies near continuous transition between the hullborne and the foilborne modes of operation. The actual "speed gap", i.e., the range between maximum stable hullborne speed and minimum foilborne speed, is quite narrow. Hullborne speeds over 16 knots were routinely set. An attempt to set 18 knots while hullborne during the heavy ship trials resulted in foilborne operation at 19.6 knots.

A maximum speed of 36.2 knots was achieved during the light ship trials. At this time engine speeds were at the maximum value of 1460 rpm but the engines were not at full power. For reasons unknown, the propellers were operating at

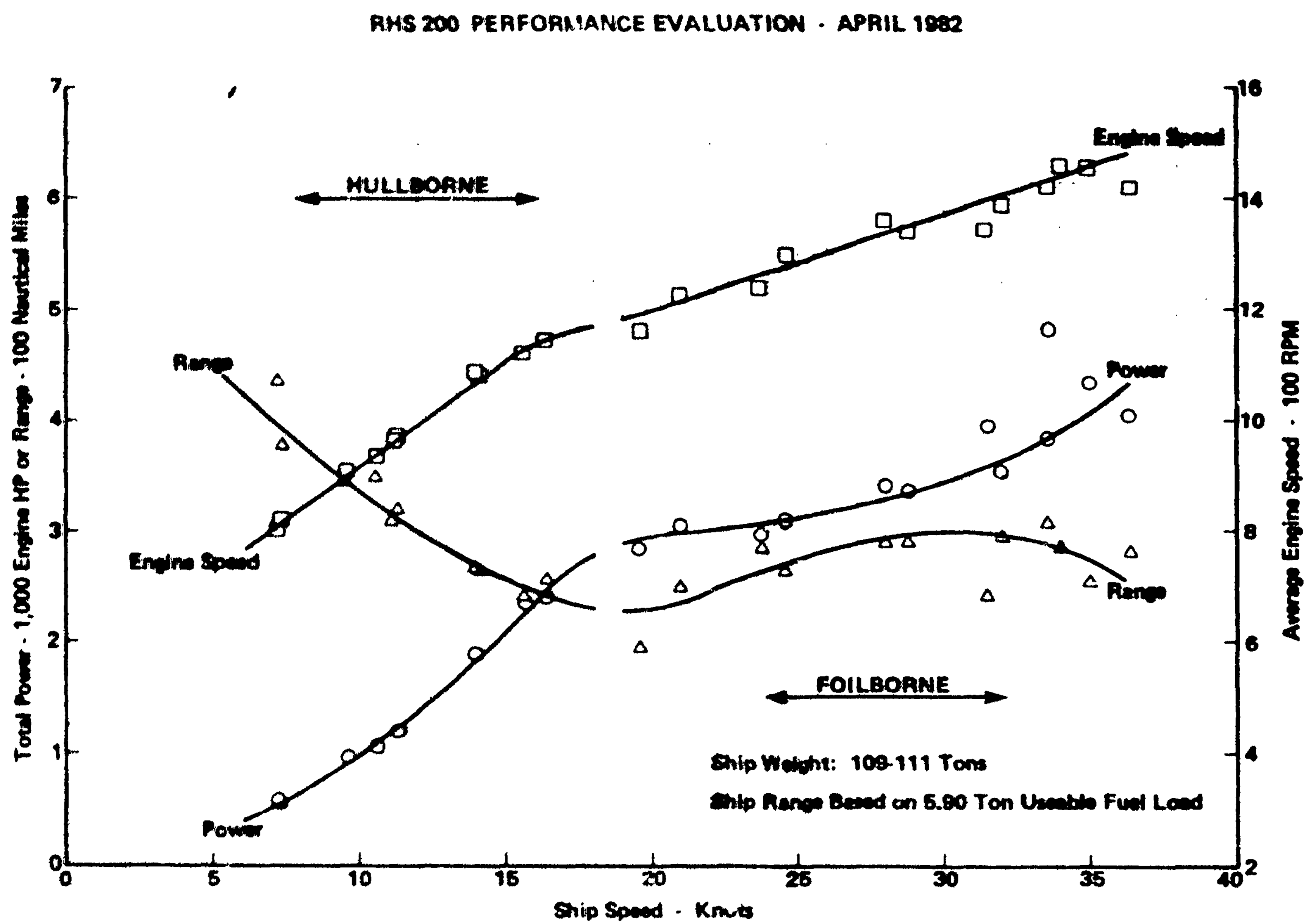

Figure 6 - Light Ship Speed and Power Performance

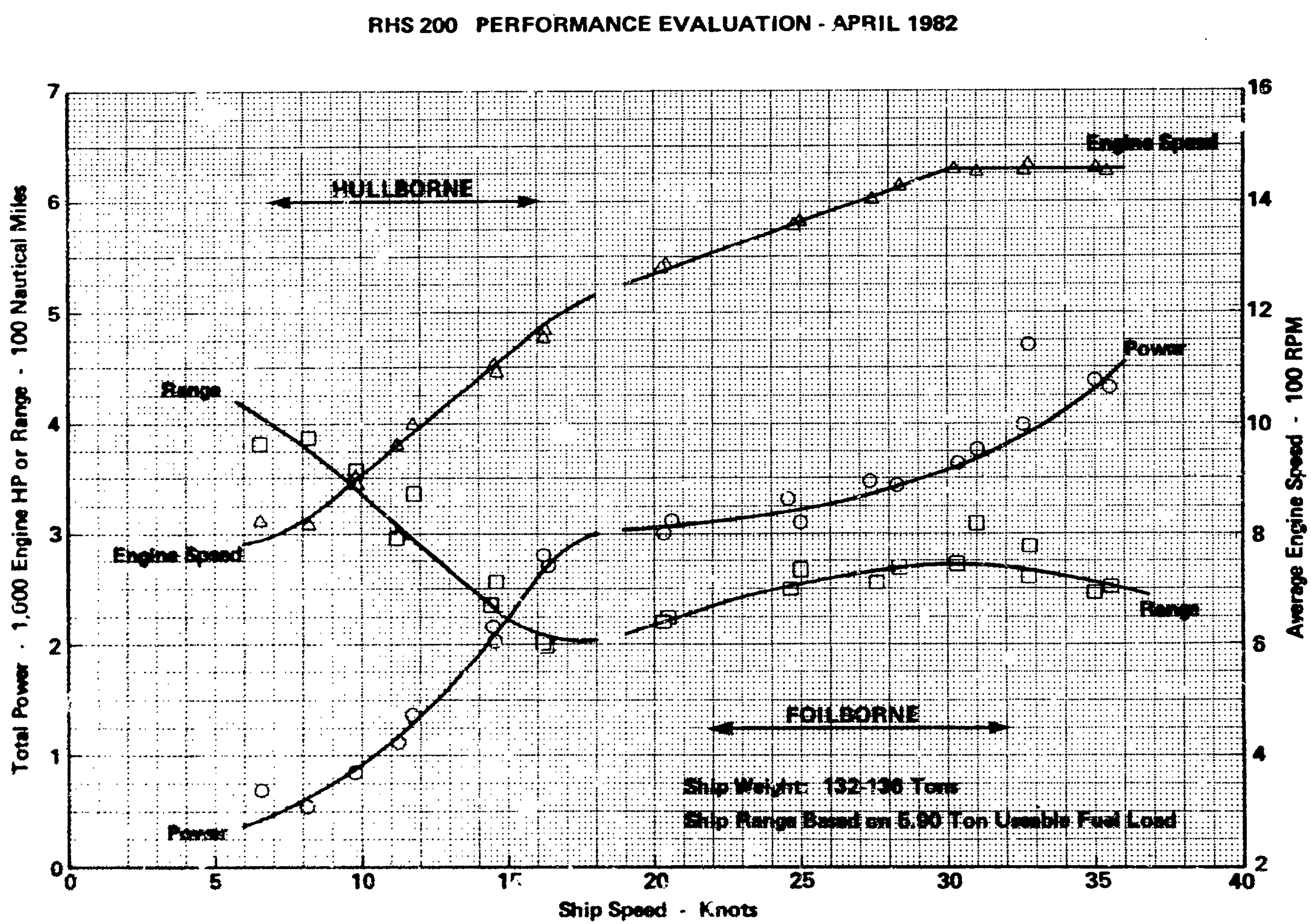

Figure 7 - Heavy Ship Speed and Power Performance

TABLE 6 - RHS 200 SPEED AND POWER PERFORMANCE SUMMARY

SHIP NOMENCLATURE	SPEED, KNOTS								
	HULLBORNE				FOILBORNE				
	7	10	13	16	20	24	28	32	36.2
LIGHT SHIP (109-111 Tons):									
Engine HP	500	960	1580	2340	2960	3010	3350	3700	4300
Engine RPM	800	915	1035	1140	1180	1260	1330	1405	1460
Thrust, lbs	6,700	11,000	16,200	21,800	23,150	21,500	20,000	19,550	19,450
Propulsive, Eff, %	27.8	34.3	39.5	44.2	46.3	50.8	49.5	50.0	48.5
Range, N.M.	414	331	283	245	220	268	294	296	255
HEAVY SHIP (132-136 Tons):									35.6
Engine HP	450	940	1650	2570	3050	3180	3390	3820	4420
Engine RPM	780	910	1040	1170	1270	1340	1415	1460	1460
Thrust, lbs	4,100	7,900	14,250	21,950	25,850	24,000	22,800	22,700	23,450
Propulsive, Eff, %	18.9	24.9	33.3	40.5	50.2	53.7	55.8	56.3	58.3
Range, N.M.	417	333	263	205	219	252	268	270	255

Notes: 1. Power and thrust values are ship totals.
2. HP in English units.
3. Range based on 5.9 tons useable fuel load.
4. Propulsive Eff as discussed in text.

reduced pitch during the lower speed tests of the heavy ship series. This resulted in higher engine speeds than those developed in the light ship tests and, maximum engine speed was achieved at approximately 30 knots. At that time the Chief Engineer used manually increased propeller pitch to progressively load the engines until the maximum heavy ship speed of 35.6 knots was reached. Maximum power settings of approximately 4300 to 4400 horsepower were achieved in the light and heavy ship tests. The power settings are the maximum loads which the Chief Engineer chose to apply during the tests. Continuous operation at these levels would apparently not be desirable since they are at alarm thresholds.

The heavy ship foilborne power levels of Figure 7 average 2.5 percent higher than those for the light ship. A 22 percent weight difference exists between the two cases. Assuming constant propulsive efficiency between the two cases, and foil lift and area trades noted in subsequent discussion of thrust data from the tests, a similar power increase could be expected in the heavy ship data. This lack of agreement may be an indication of the overall accuracy of the speed and power data. These data were re-examined ignoring the power "adjustment" procedures discussed in the Data Reduction Section. The unadjusted power data contained increased scatter and did not provide improved definition of light-to-heavy ship trends.

The foilborne range curves in Figures 6 and 7 are also not fully consistent with the light-to-heavy ship 2.5 percent increase in power requirements. Range for the heavy ship configuration is typically 6 to 9 percent less than that determined from the light ship trials. The light and heavy ship maximum foilborne ranges of 296 and 270 nautical miles respectively both exceed the advertised "Cruising Range" of 200 nautical miles cited in Reference (1). The ground rules used in calculating the reference range are unknown. The ground rules used in this study were optimized to simplify the calculation, a procedure which also provided optimistic range estimates. It was assumed that the full fuel load of 5.9 tons was 100% available. In addition, no deduction was included to account for the fuel consumption of the diesel-powered ship's service generator(s).

Port engine fuel flows were not measured during the trials. For range calculation purposes they were estimated from starboard engine fuel flows on a

basis of the ratio of the power levels of the two engines. Net fuel flows to the starboard propulsion diesel engine as determined from the difference of measured supply and return fuel flows during the trials are given in Figure 8. As noted in the figure the faired curves have been computed from the faired range curves of Figures 6 and 7. This is an expedient adopted to ensure numerical consistency when equivalent data are presented using different units or formats. The fuel flow data are consistent in the light-to-heavy ship context. They should be used if corrections to, or recalculation of, the range curves are considered.

Starboard engine Specific Fuel Consumption (SFC) is given in Figure 9. The data reflect operation along the load line imposed by the CP propeller. The light and heavy ship data are essentially in one-to-one agreement as should be expected. The broad base of the curve, i.e., little change in SFC over a relatively wide range of engine power, reflects a typical match of a diesel engine to a propeller. The minimum SFC of nominally 0.375 is acceptably close to the 0.36 value typically considered to be an optimum for high speed diesel engines.

The RHS 200 propeller shafts were instrumented to measure shaft thrust at the output side of the reduction gearboxes. The thrust data obtained during the calm water speed and powering trials are given in Figure 10. These data have been developed using procedures which paralleled those used in the adjustment of the power data. That is, port thrust values were estimated as rpm-squared functions of starboard thrust. The procedure was adopted due to a lack of consistency in the port thrust data and it resulted in a reduction in data scatter. The thrust data have not been corrected for losses at the stern tubes or strut bearings. Similarly, the shaft angle corrections required to resolve net propeller thrust into lift and drag components have not been applied.

Throughout most of the hullborne operating regime the light ship thrust data are markedly higher than those for the heavy ship case. In comparison of Figures 6 and 7 it can be found that the hullborne heavy ship powering requirements are at least equal to, or higher than, those of the light ship. In addition, the heavy ship propulsive efficiency curve of Figure 10 is discontinuous between the hullborne and the foilborne operating regimes. These facts all

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

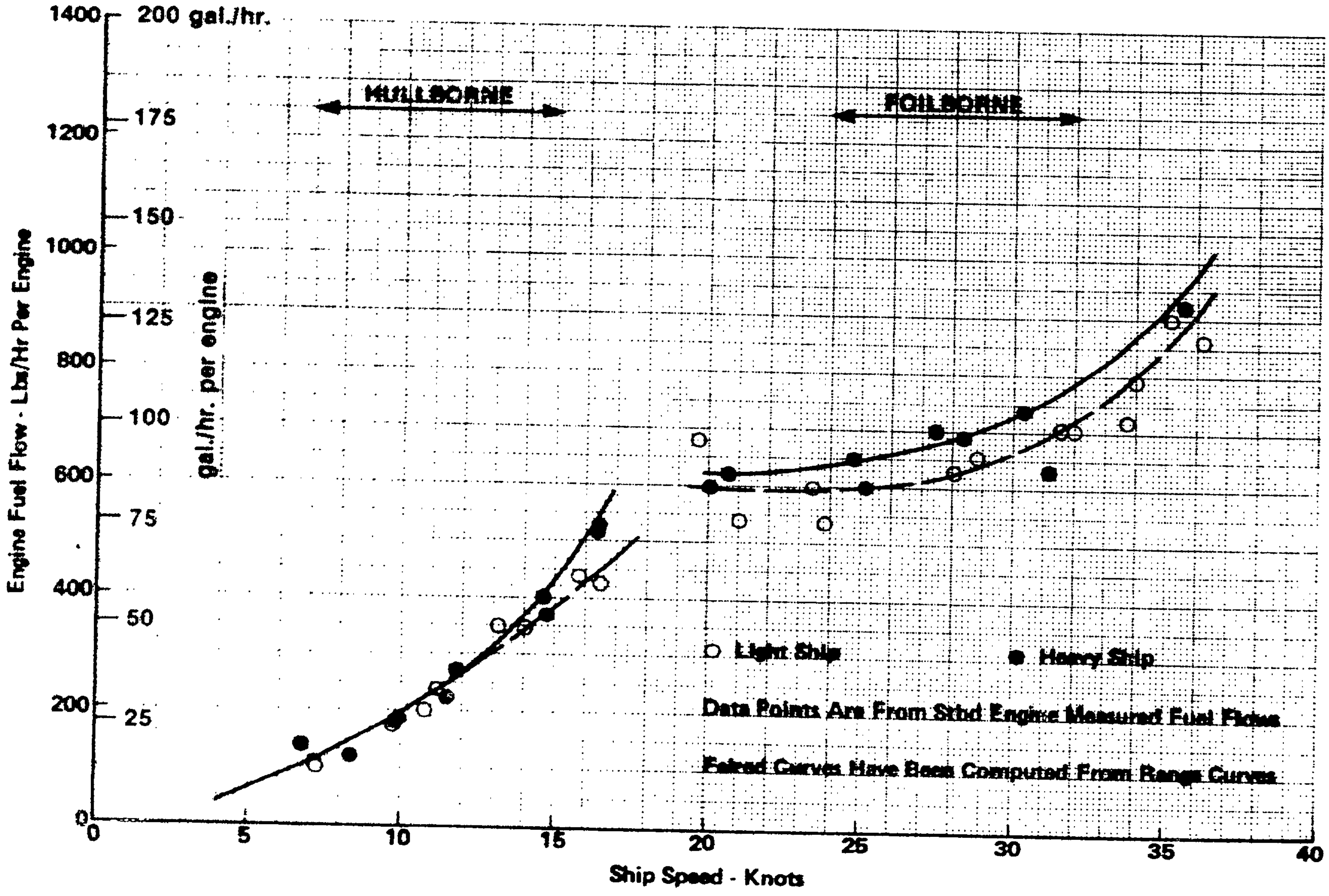

Figure 8 - Propulsion Fuel Consumption

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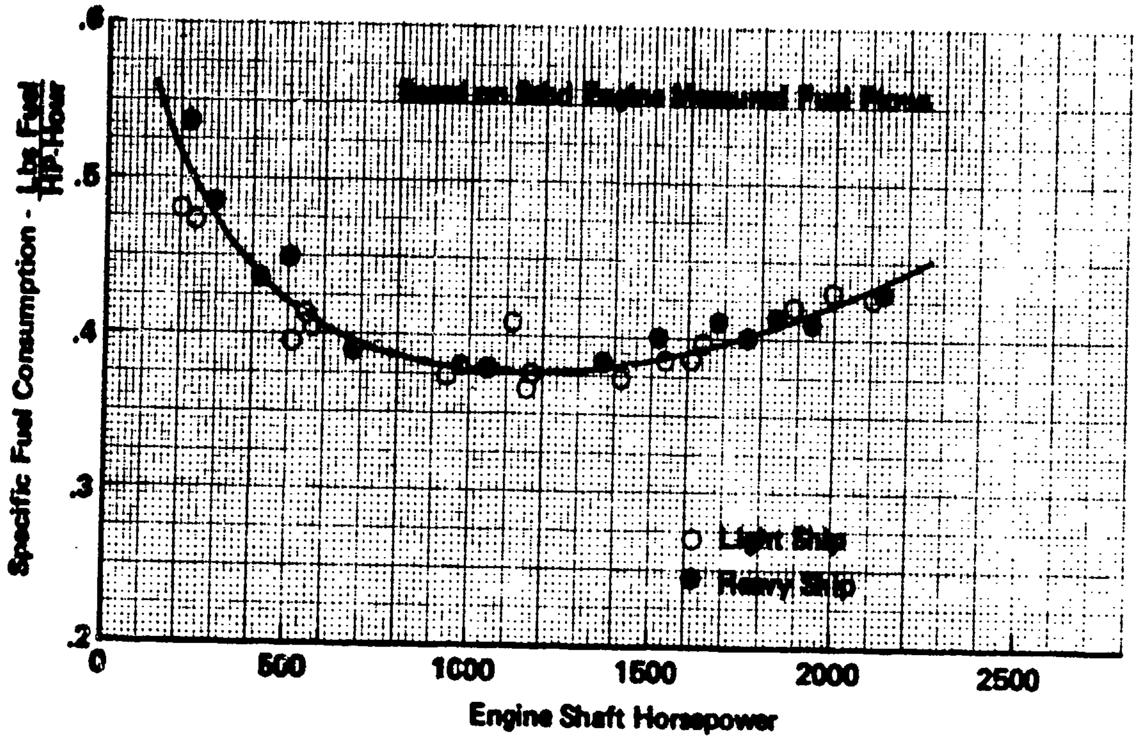


Figure 9 - Specific Fuel Consumption

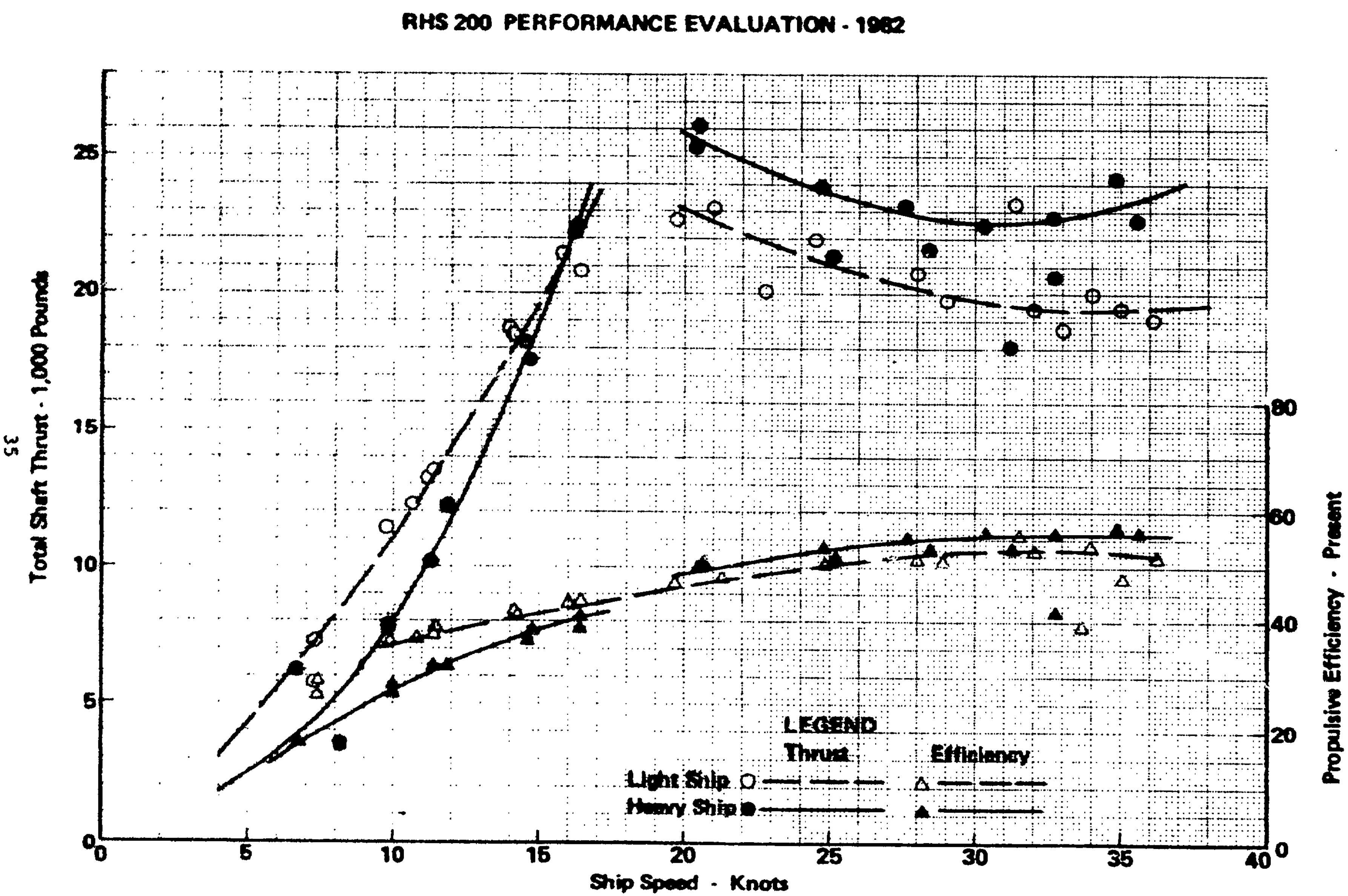


Figure 10 - Thrust Data Comparisons and Propulsive Efficiency

support a conclusion that the thrustmeters were not providing valid data during the heavy ship hullborne tests. The source of the discrepancy was not found through full re-examination of the data.

The foilborne thrust curves of Figure 10 display correct relationships in the light-to-heavy ship context. In addition, the faired curve for the heavy ship data is between 12 percent at 20 knots, to 20 percent at 35 knots, higher than the light ship thrust. In the strictest sense, if a surface-piercing hydrofoil were operating at constant lift coefficient values, a 22 percent increase in ship weight should result in at least the same percentage increase in drag. The foilborne trim data of Figure 11 indicates that the foil systems were operating at higher angles of attack and consequently, at higher lift coefficient values during the heavy ship tests. In this instance the one-to-one relationship between increased weight and increased drag would be reduced and heavy ship lift-to-drag ratio should be higher than that for the light ship. This is typically the case with the data of Figure 10. Light ship lift-to-drag ratios. with drag defined by using the cosine of the 15 degree shaft angle to correct thrust, vary from 11.1 at 20 knots to 13.2 at maximum speed. Heavy ship lift-to-drag ratios vary from 12.0 to 13.3 over the same speed range.

The above comments support the conclusion that the light-to-heavy ship increments in thrust given in Figure 10 are correct. In view of the error in the hullborne data, further analysis would be required to confirm the magnitudes of the foilborne thrust levels. The most direct approach to such analysis would be a complete calculation of foilborne drag for the ship. The hydrodynamic and geometric definition of the foils systems necessary for this level of analysis are not available. A similar situation impedes the interpretation of the foilborne trim data of Figure 11. Both the light and heavy ship data sets display a marked depression at speeds of approximately 28 knots. It is postulated that the speed related reductions in pitch angle are the results of inherent forward and aft foil system lift and area trade-offs which occur with increasing speed. The basis for the fact that foilborne light ship trim is less than heavy ship trim is also believed to be inherent in the properties of the foil systems. A shift in the longitudinal center of gravity between the two weight conditions would also

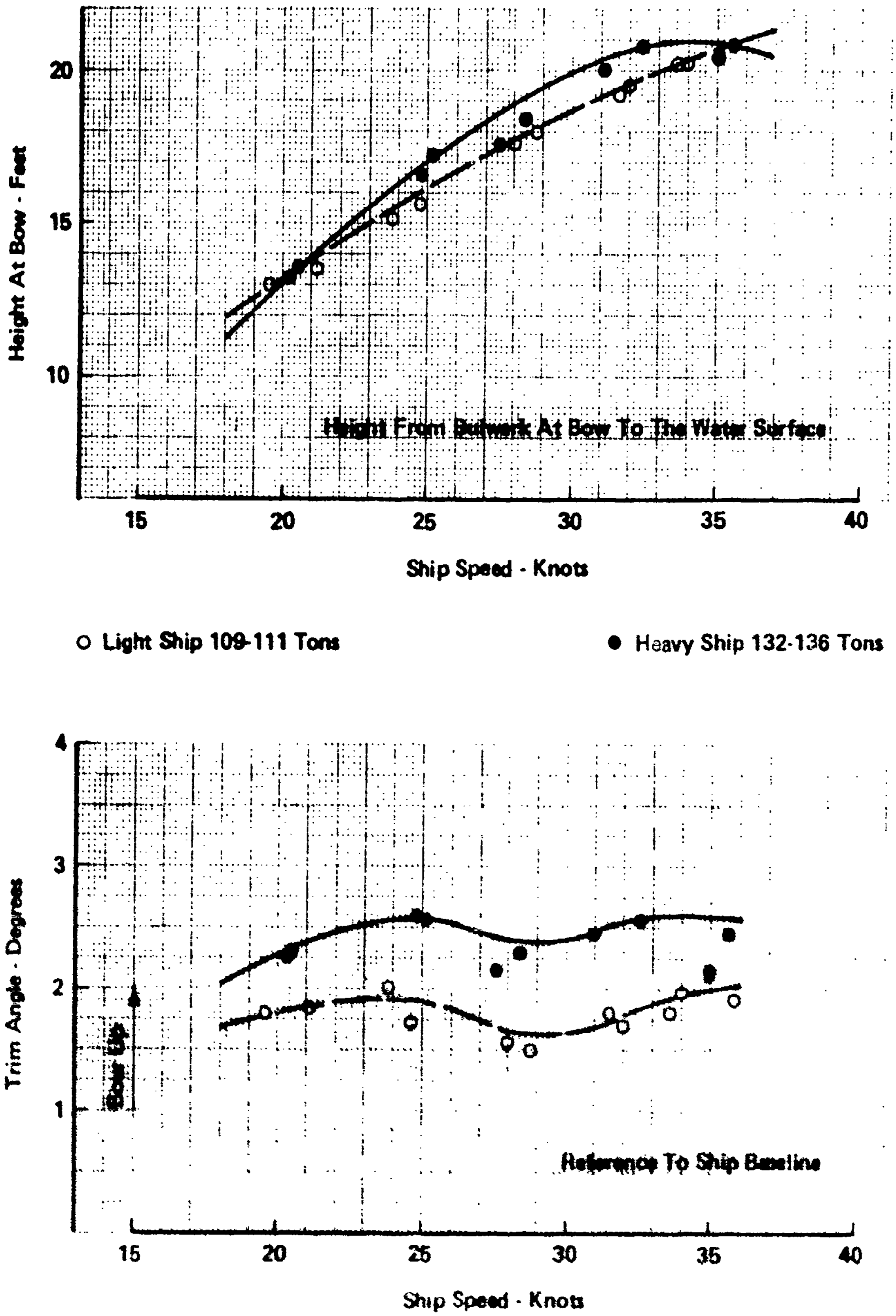


Figure 11 - Foilborne Height and Trim

influence trim. The trim data of Figure 11 is accepted as valid. The reduced trim regions of the curves was established by repeated test points within each weight condition.

Estimates of the operating propulsive efficiency of the RHS 200 are included in Figure 10. The data have been defined using the equation for efficiency included in Table 5. The only losses included in the derivation of propulsive efficiency is a 2 percent correction applied to allow for the reduction gearboxes in place between the torquemeters and the engines. It was assumed that minor thrust losses in the stern tubes and strut bearings would be equivalent to thrust deduction effects on the after foil system. As was noted in the description of the RHS 200 the propellers are a supercavitating design produced by KaMeWa. Based on KaMeWa successes in other high speed propeller installations propulsive efficiencies well in excess of 60 percent would be expected. The relatively low efficiencies in Figure 10 could result from power estimates which were too high, thrust data which is too low, or actual low propeller efficiencies. In view of Rodriquez expressed concern regarding propeller efficiency, a propeller selection exercise was performed to estimate efficiency levels and to assess off-design operation of the supercavitating, CP propellers. KaMeWa 398B model propeller data was used in the selection exercise. The 398B design is older than that used for the RHS 200. A propeller was selected which would absorb full engine power at 850 propeller rpm at 36 knots. Resulting light ship propulsive efficiency varied from 53 percent at 20 knots to 63 percent at 36 knots. The heavy ship efficiency estimates were slightly lower; 53 percent at 20 knots and 61 percent at 36 knots. On the basis of these results it must be considered that the installed propellers may actually be operating at relatively low efficiencies.

The data of Figures 5 through 11 represent normal, steady-state, operational characteristics of the RHS 200 as defined from the trials. Additional tests were performed to determine the effect of trim on foilborne speed and power and to assess single engine hullborne performance. Both of these test series were performed at the heavy ship weight condition. In the trim tests, foilborne speed and power data were obtained with the ship operating at increased and decreased trim angles of approximately one degree. The SAS was used to provide the necessary control of ship trim. In the increased trim tests the forward

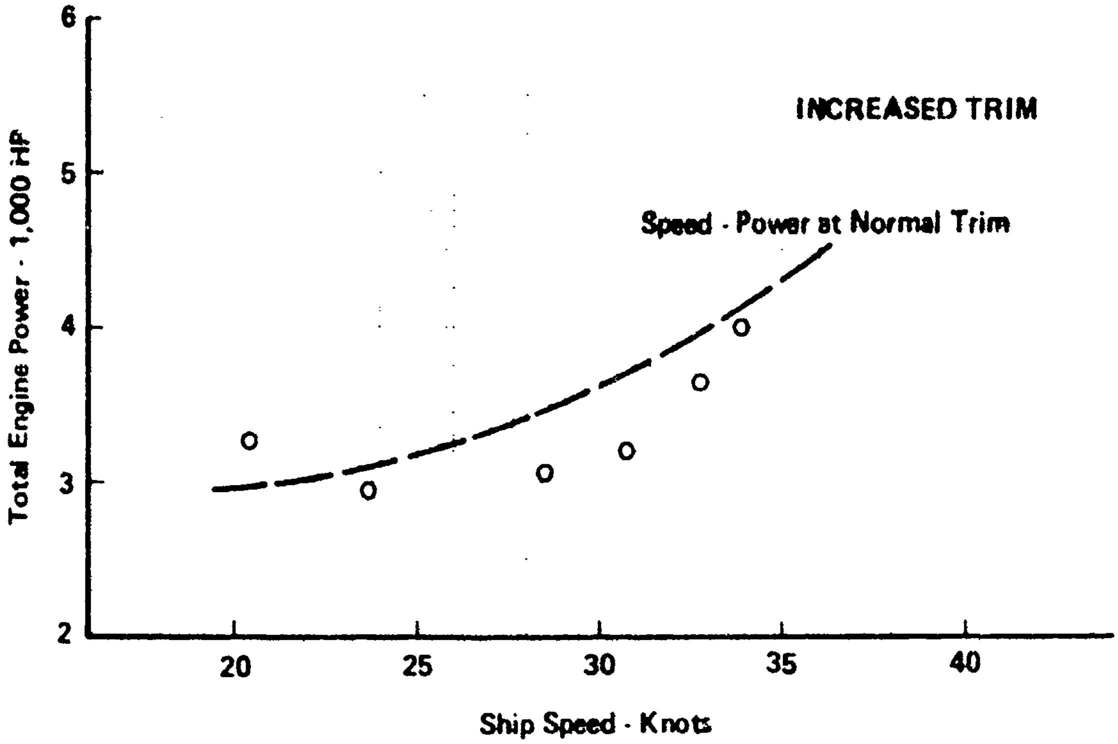
flaps were deflected down by approximately 7 degrees to provide increased lift at the forward foil. The aft flaps were deflected down by approximately 10 degrees during the reduced trim tests. The speed and power results of the tests are given in Figure 12. The data indicates that some improvement in foil system drag may result when operating with increased trim at off-design speed. Off-design operation with reduced trim incurs definite drag penalties.

Single engine hullborne trials were conducted to determine speed and power capability in the event that one shaft was disabled or suffered a loss of power. During the tests the port engine was shut down, the shaft was de-clutched and propeller pitch was set to near zero. The results of the tests are given in Figure 13. The maximum speed attained was 11.5 knots and was limited by occurrence of overload alarms on the starboard engine. The fact that engine power levels were well below maximum power is partially the result of the higher torque loads which a propeller will develop at high rpm at low ship speed. In the current installation the propeller pitch load control unit functioned to prevent engine overload by maintaining reduced propeller pitch. The Chief Engineer used manual pitch control to load the starboard engine as heavily as possible. The single engine performance capability of the RHS 200 could provide a reasonable mode of emergency operation.

Takeoff Evaluations

The calm water takeoff trials considered three types of takeoff in both the light and the heavy ship weight configurations. The tests included minimum power takeoffs, normal takeoffs using the programmed SAS Takeoff mode, and takeoffs with zero flaps.

The minimum power tests were intended to define the minimum power required to achieve foilborne operation. The information can be used in comparison with normal takeoff power requirements to define excess takeoff power capability. These takeoffs were performed with the SAS in the Takeoff mode by establishing steady-state operation at an engine speed which was approximately 200 rpm below the point where a normal takeoff would occur. The throttles were advanced to increase engine speed by 50 rpm increments and ship speed was allowed to stablize after each throttle increment was applied. Steady-state data was obtained at



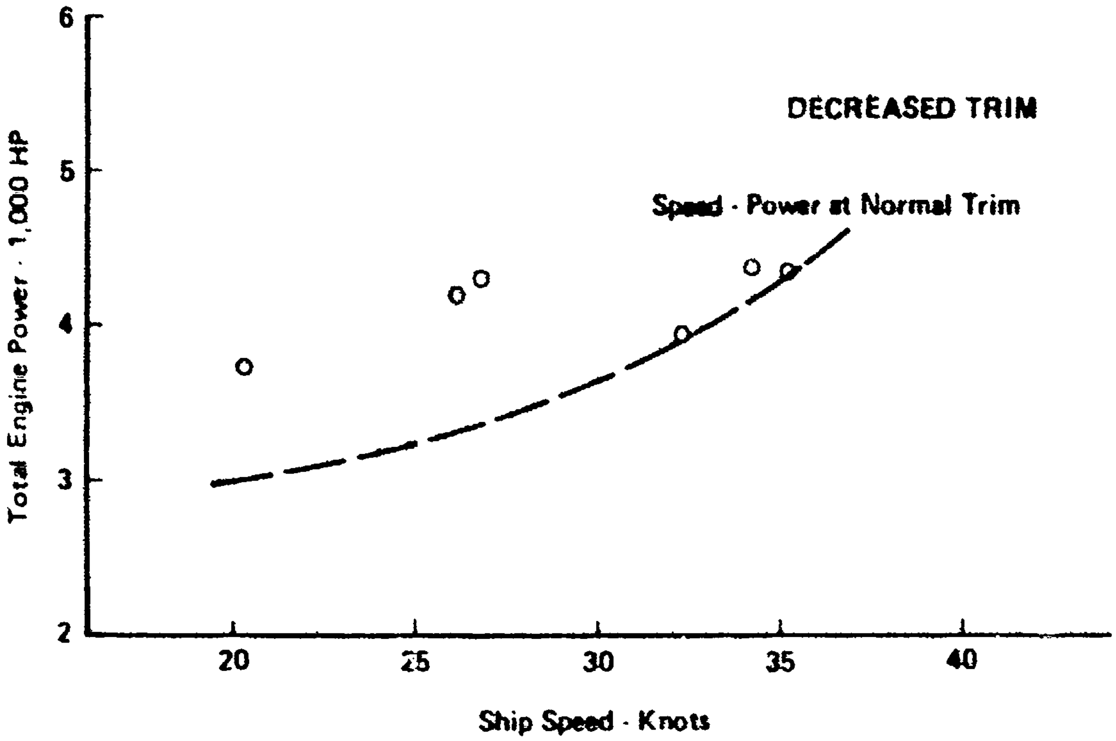


Figure 12 - Effect of Ship Trim on Foilborne Speed-Power

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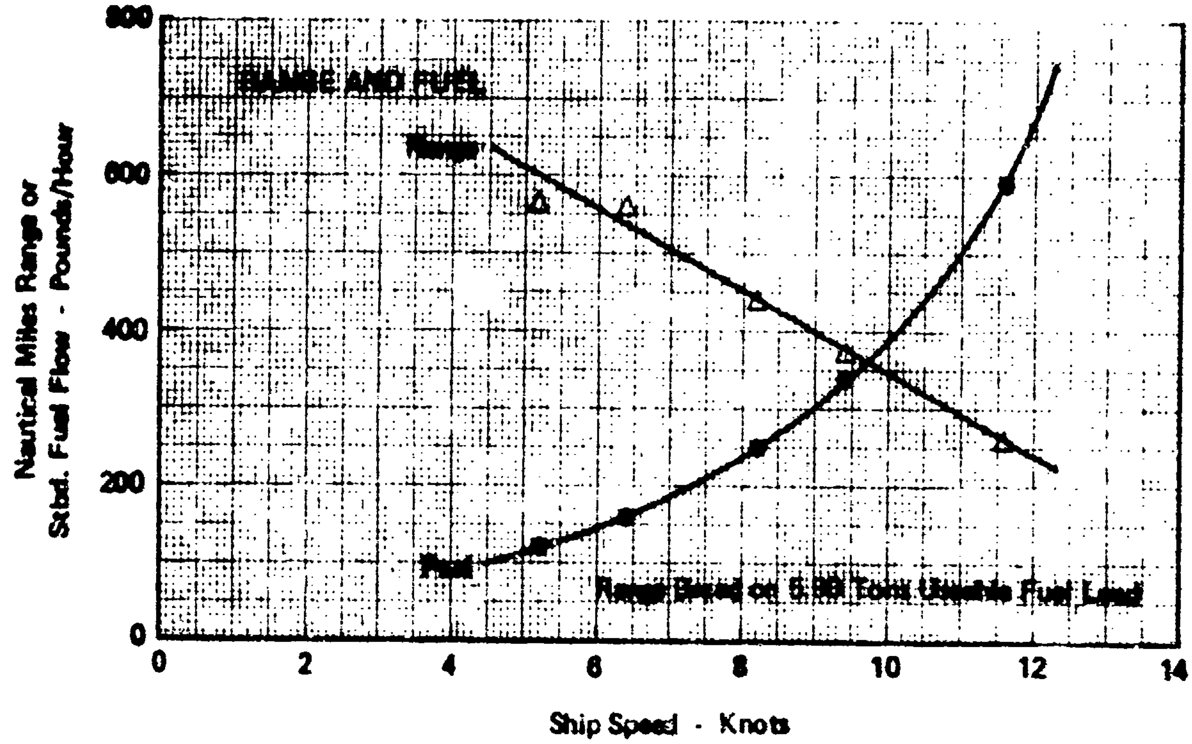

Ship Weight: 132 - 136 Tons

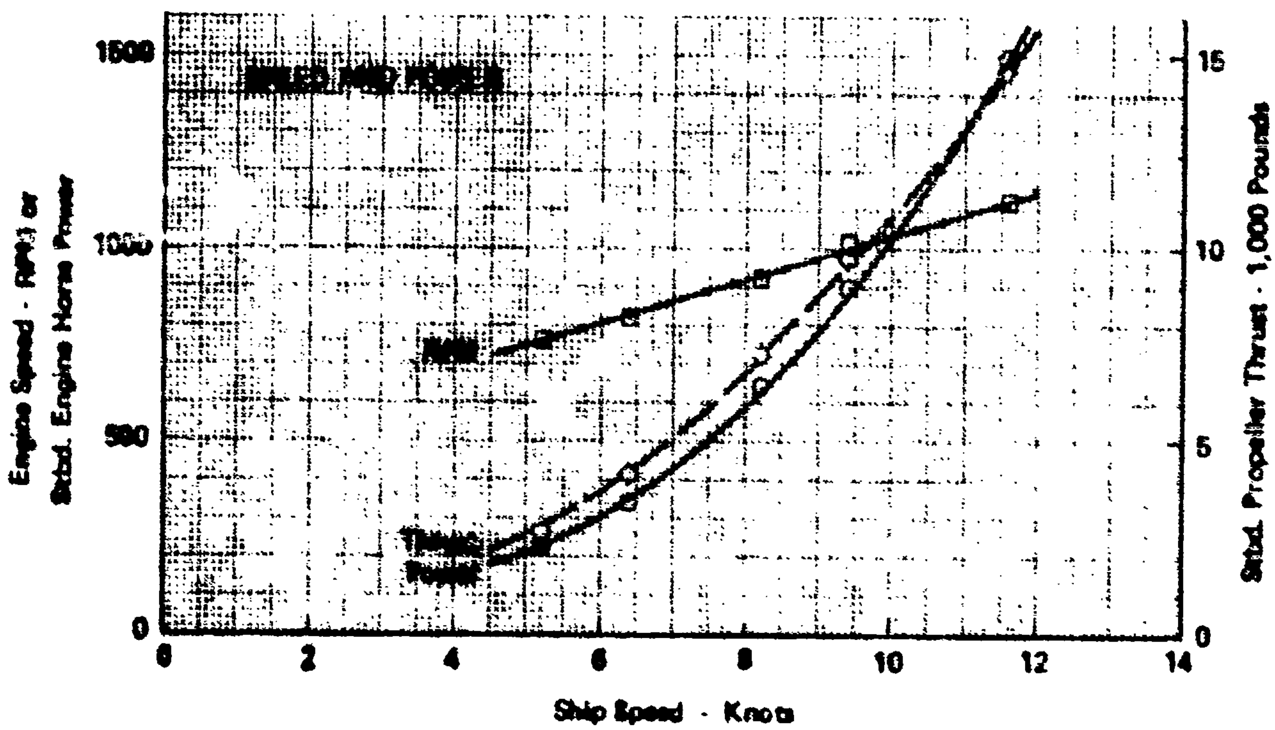

Figure 13 - Single Engine Hullborne Performance

each stable increment. The minimum power takeoff point was identified when the ship failed to stabilize at a hullborne speed and achieved foilborne operation.

The results of light ship minimum power takeoff are given in Figure 14. The data are for two separate test series. A third repeat of the tests did not produce significantly different data. The point of maximum required power was at 20 knots while the propellers were absorbing the equivalent of 2860 engine horsepower. In all of the light ship tests, stable hullborne operation could not be maintained if the throttles were advanced as little as 10 to 20 rpm above an engine speed of 1200 rpm. The ship accelerated in speed, bow height increased an average of 3 feet without a significant change in trim and stable foilborne operation was achieved.

The relatively sharp reductions in thrust and power in Figure 14, after takeoff, reflect changes in ship drag with foilborne operation and changes in propeller loading which would occur with an increase in speed of advance at constant rpm. The propeller load reductions appear to be greater in this instance than what would normally be expected. The effect of the change in elevation on the output of the speed transducer has been accounted for in the derivation of the final data points. There were no significant changes in propeller pitch between the points of maximum load and maximum speed. There is some possibility that the operating characteristics of the propellers were slightly altered by increased cavitation as the ship became foilborne and propeller submergence was decreased.

The torque and thrust data derived from the heavy ship minimum power takeoff tests were too erratic to warrant their inclusion in this report. In those tests minimum power takeoffs also occurred immediately above 20 knots while attempting to set shaft speeds slightly in excess of 1200 engine rpm. The data provided some indication that total power levels were at 3100 horsepower at the point of takeoff. Marked reductions in propeller loads were again present after the takeoff occurred.

The normal takeoff tests were performed following the straight forward procedures used in routine operation of the ship. The SAS was aligned to the Takeoff mode which commands 10 to 12 degree deflections of the forward flaps. The throttles were then advanced from idle to full power at the maximum rate

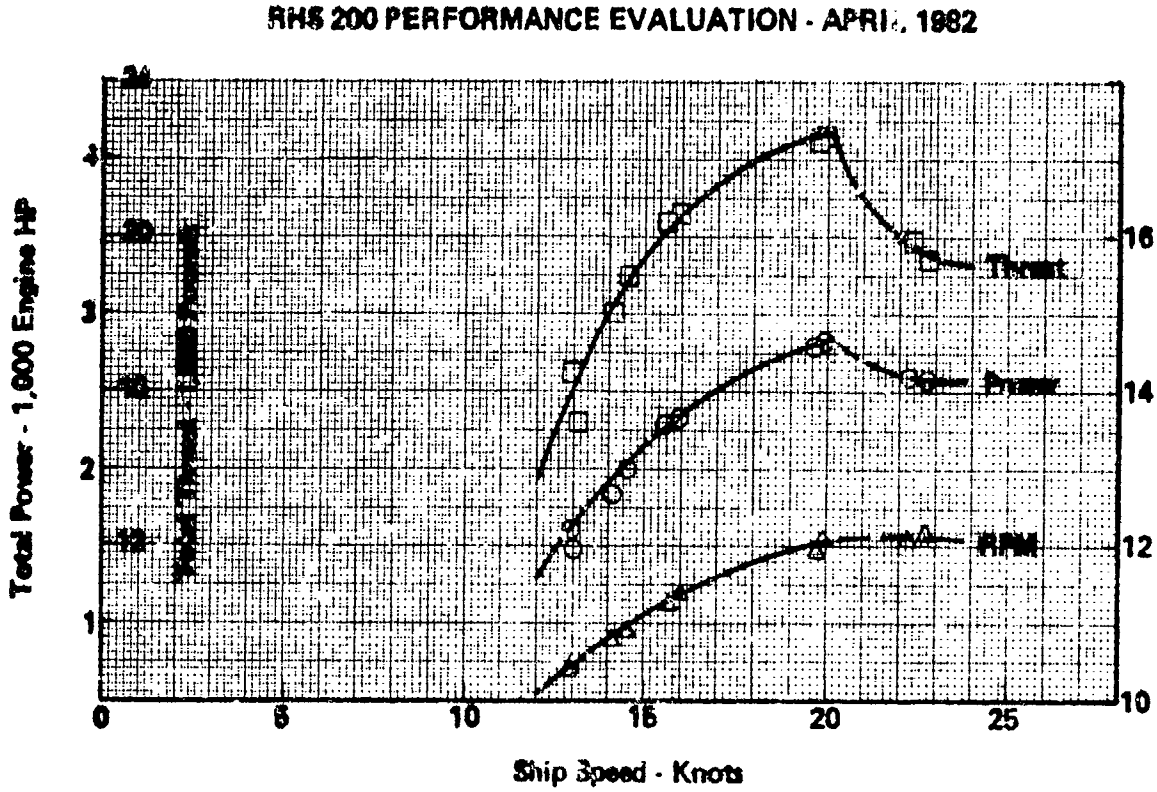

Figure 14 - Light Ship Minimum Power Takeoff

which the Chief Engineer deemed advisable. During the takeoff cycle, the added forward foil lift, generated by the flaps, increases ship trim and results in added lift from both the forward and aft foil systems. The ship simply accelerates through the takeoff and reaches steady state foilborne operation at a speed equivalent to the power settings. Typically, the SAS is realigned to the Automatic mode as speed increases above 25 knots. The tip panels of the forward foil on the RHS 200 are marked to define the plane of the keel at that location along the hull. The point where this mark broached the water surface was identified as the actual point of takeoff. During the trials, the times required to reach takeoff and to reach a speed of 30 knots from the idle condition were noted.

Zero flap takeoffs were performed to evaluate the effect of SAS assist on takeoff performance. These tests were conducted in the same manner as the normal takeoff series with the exception that the SAS Zero Flap mode was selected prior to the takeoffs. Three light ship and two heavy ship zero flap takeoffs were conducted.

Light ship normal takeoff characteristics, as defined by one of the three essentially identical tests of the series, are given in Figure 15. Similar data for a light ship takeoff with zero flaps are given in Figure 16. Heavy ship normal and zero flap takeoff characteristics are given in Figures 17 and 18 respectively. The data for all four cases are sufficiently in common that detailed discussion of each case would be redundant. A summary comparison of the faired power and elapsed time curves from the four takeoff cases is given in Figure 19.

All of the takeoff tests were initiated while at idle power. This condition typically resulted in a ship speed of 5 to 7 knots with propeller pitch settings of 35 to 40 percent. The engines responded very rapidly to the advancement of the throttles producing abrupt increases in both shaft speed and power. By the time that ship speed was increased to approximately 10 knots propeller pitch had been increased to the 95 percent region. From that point on there were no further significant changes in propeller pitch and the takeoffs were largely fixed-pitch operations. As is apparent from Figure 19 there were no substantial differences in the application of power in any of the takeoffs. The largest areas of difference in power occur below 13 knots. Peak power levels were reached in the 15 to 18 knot speed region. No information is available which

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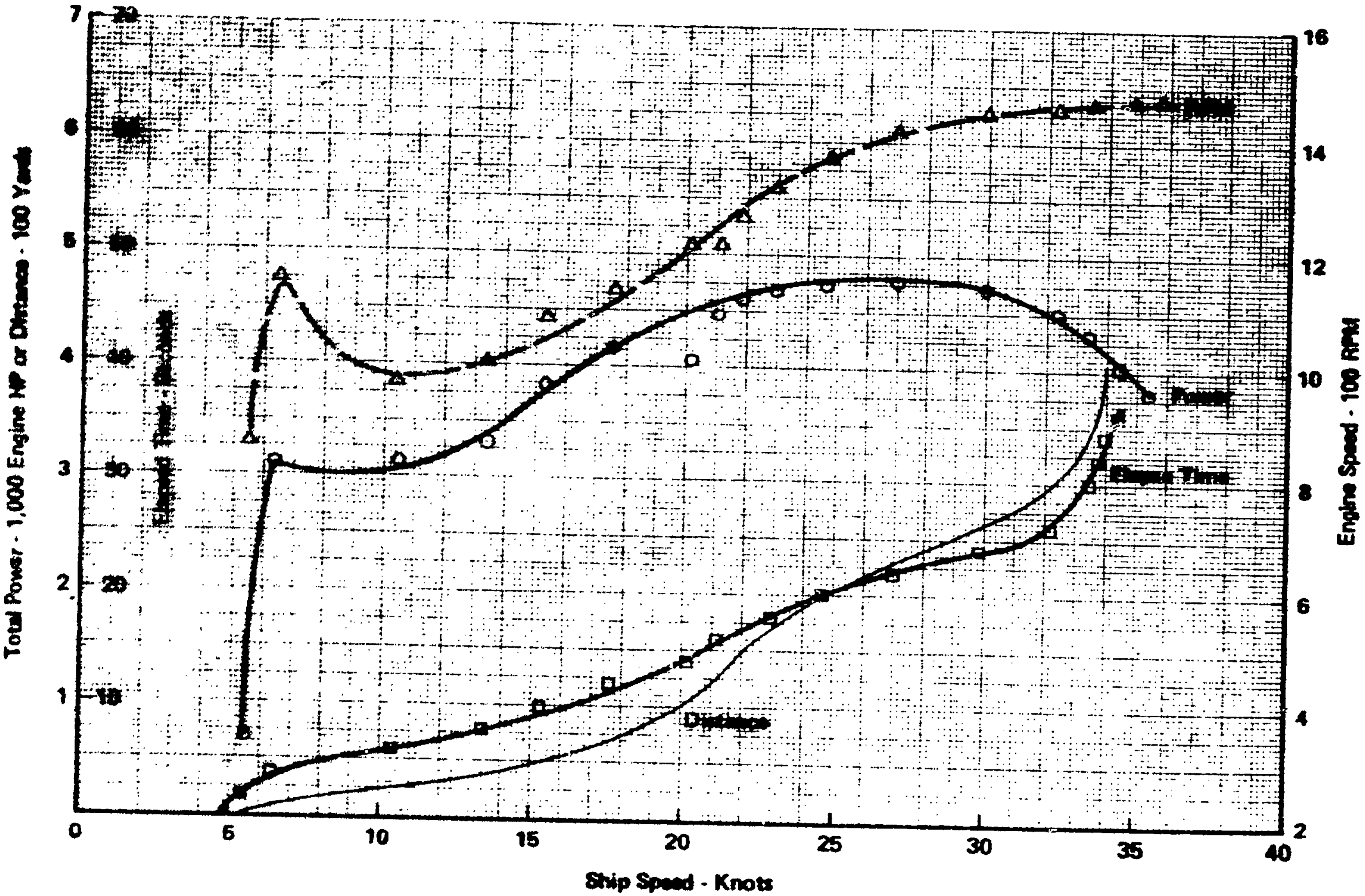

Figure 15 - Light Ship Takeoff Performance

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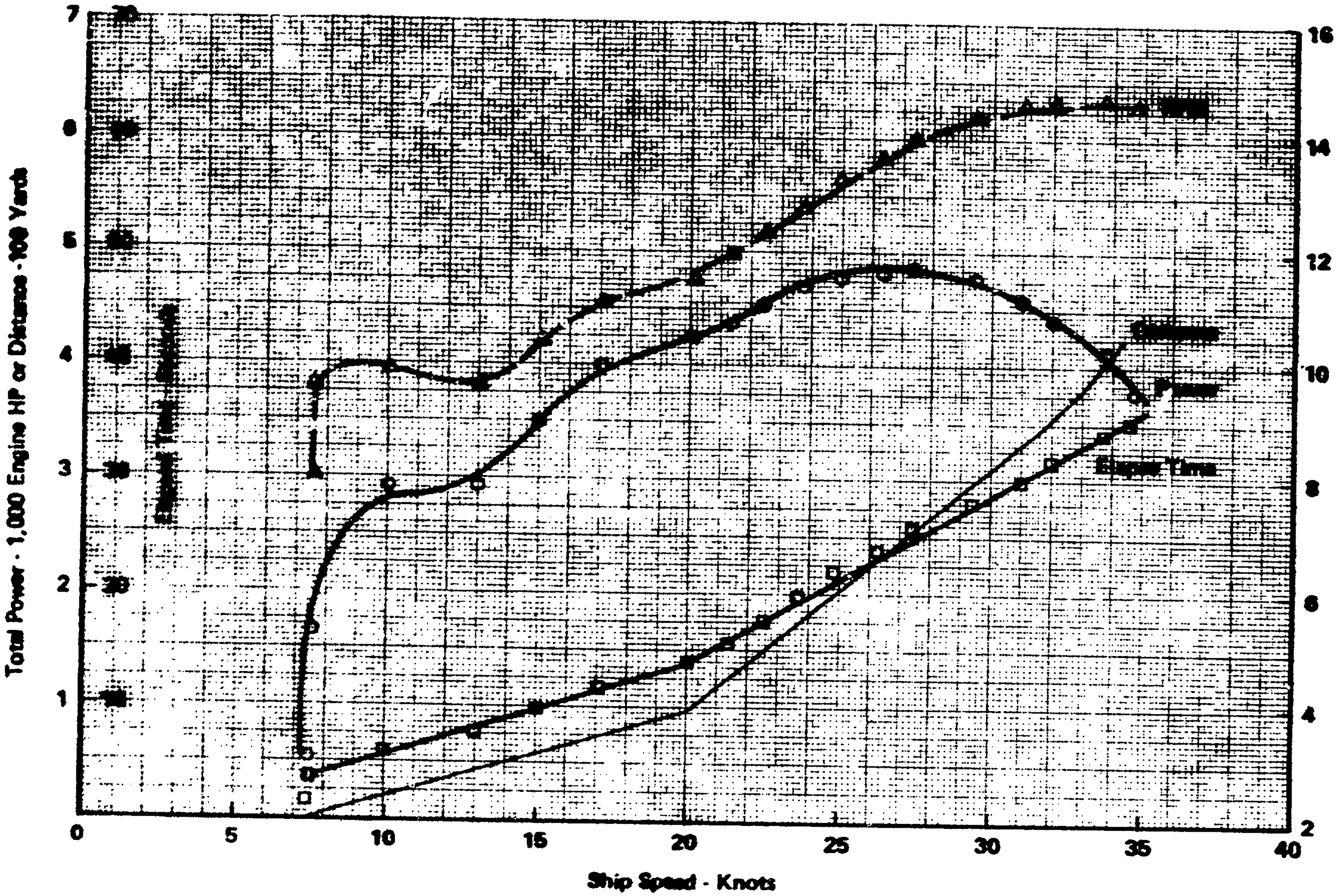

Figure 16 - Light Ship Zero Flap Takeoff Performance

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

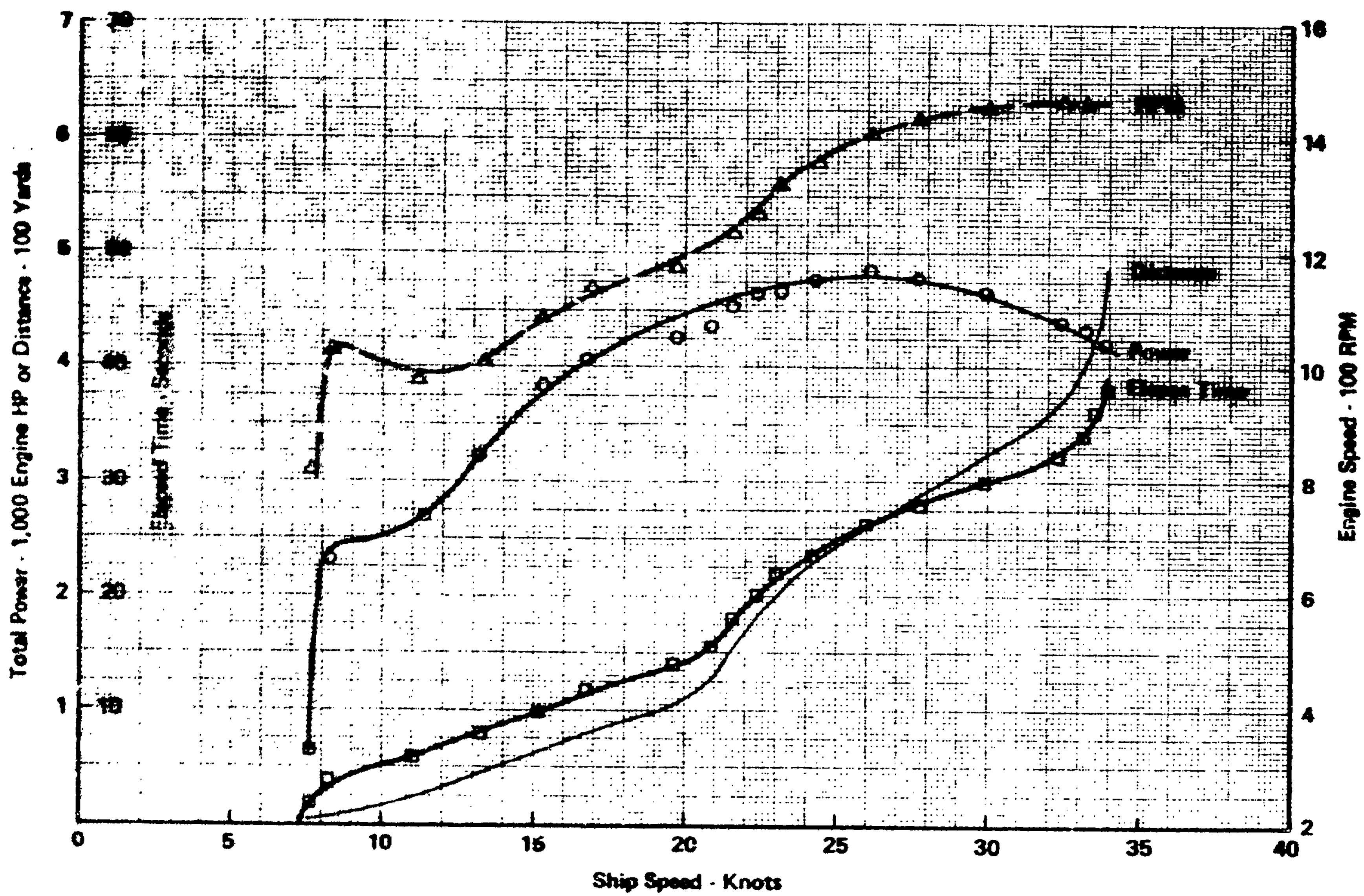

Figure 17 - Heavy Ship Takeoff Performance

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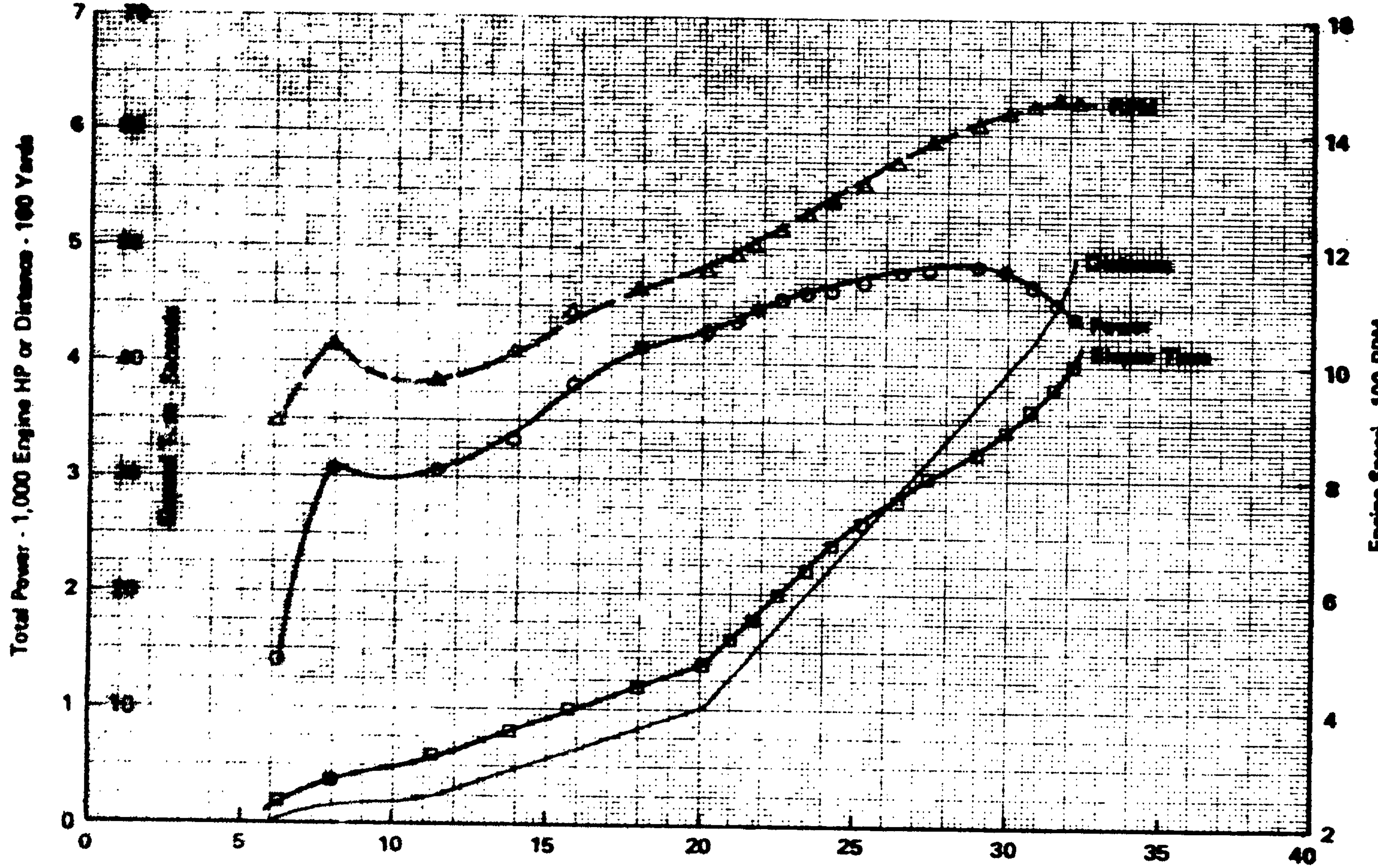


Figure 18 - Heavy Ship Zero Flap Takeoff Performance

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

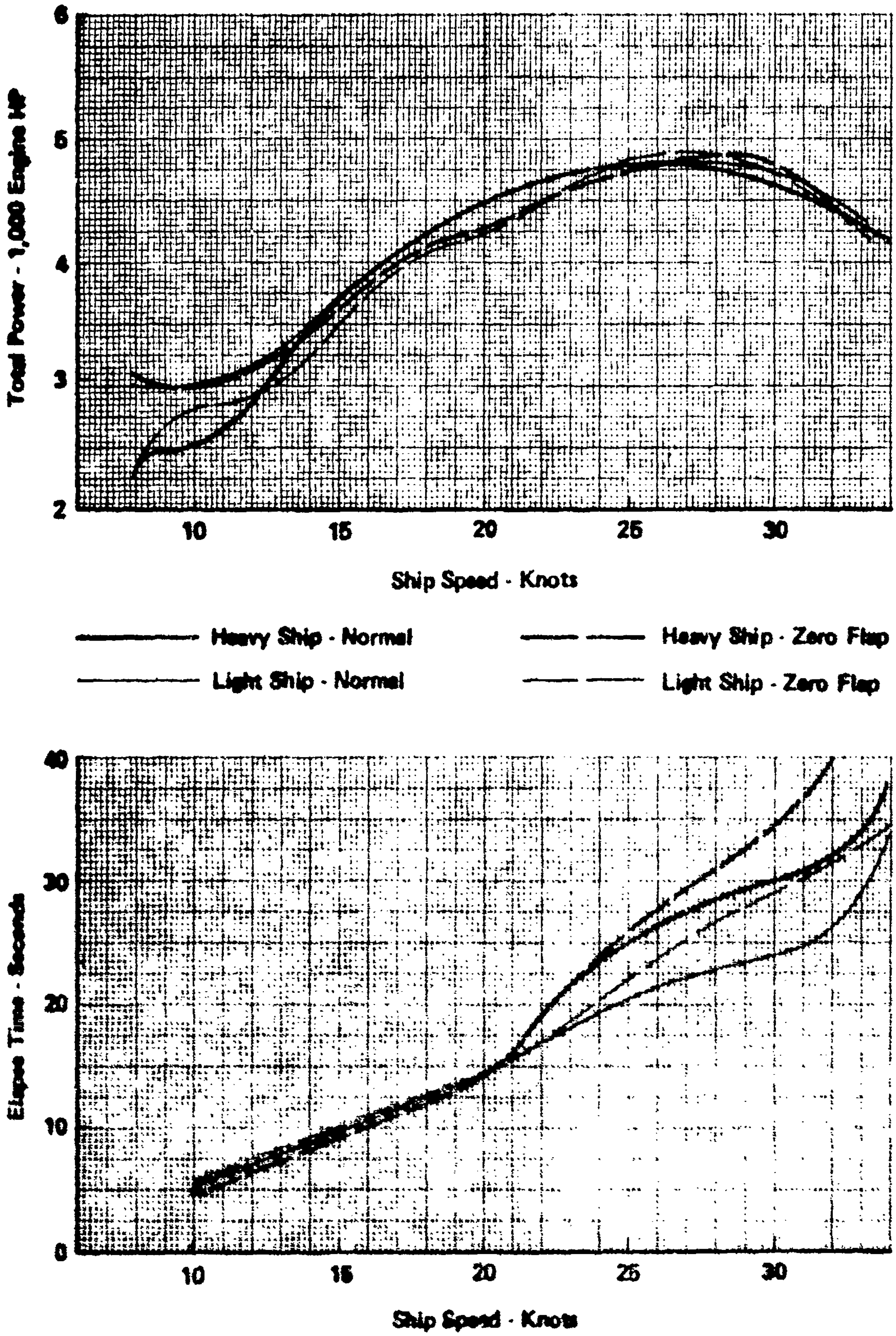


Figure 19 - Light and Heavy Ship Takeoff Comparisons

defines engine operational limits or the programmed interaction of the propeller load control units and the engines. The fact that there is little difference between the power levels in all of the various takeoffs could result from either efficient manual control by the Chief Engineer or from engine load limits specified within the load control units.

The effects of ship weight and SAS assist on takeoff performance were minimal during the early hullborne stages of the takeoff tests. In the preparation of Figure 19 the time versus speed curves of Figures 15 through 18 were shifted vertically to permit all the curves to pass through a time of 5 seconds at 10 knots. This adjustment, which was minor in all cases, allows better comparison of ship acceleration throughout the takeoffs. In all cases acceleration was essentially constant until nominal speeds of 10 to 21 knots were reached. Above this speed the effects of ship weight and SAS assist become more apparent.

Trim attitudes of the ship during the takeoffs are given in Figure 20. The increased trim effect of the SAS controlled forward flap deflections is clearly evident in both the light and heavy ship tests. There is little difference between the light and heavy ship trim curves with the SAS Takeoff mode engaged. With the flaps zeroed the heavy ship tended to approach the takeoff at flatter trims until ship speed was over 20 knots.

During the data reduction process attempts were made to use measured bow height and trim angle in conjunction with ship and foil system geometries to identify the point where full ship weight was supported by the foils. Satisfactory results were not achieved. The time and speed data which was recorded during the trials offers the best means for comparison of the various takeoffs. Average values of these data are presented in Table 7. The distance values of the table are based upon average values of the time and speed data. The most noticeable result is the difference between heavy ship normal and zero flap takeoff times. The use of the SAS provided a 70 percent reduction in heavy ship takeoff time, however, to place the data in perspective it is noted that takeoff times on the order of 15 seconds should be considered outstanding and 25 seconds as very acceptable.

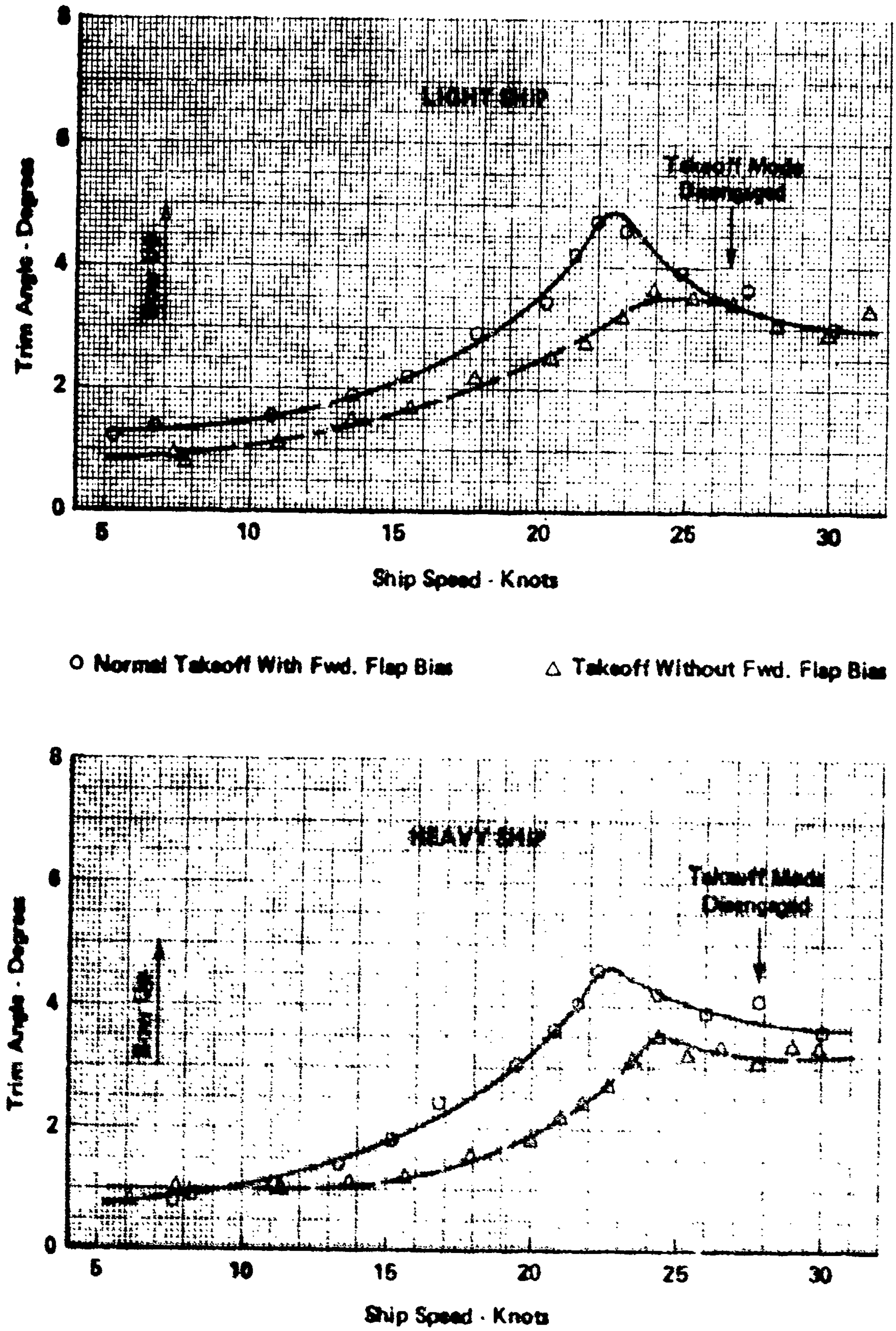


Figure 20 - Ship Trim During Takeoff

TABLE 7 - TAKEOFF PERFORMANCE SUMMARY

SAS MODE	LIGHT SHIP		HEAVY SHIP	
	AUTOMATIC	ZERO FLAP	AUTOMATIC	ZERO FLAP
Time to Takeoff, Sec	14.3	16.7	15.5	26
Takeoff Speed, Knots	20.6	23.9	22.1	25.2
Distance, Yards	83	112	96	184
Time to 30 Knots, Sec	25	26	27.5	34.5
Distance, Yards	159	183	184	250

The speed data for the proceeding takeoffs contain unknown, height-related, discrepancies which are potentially most severe in the 20 knot regime. As noted earlier, the calibration of the speed log considered separate hullborne and foilborne modes of operation. The TDAS computer was programmed to select the following calibration curve at transducer output voltages equivalent to 19.3 knots. This procedure, which minimized the effect of elevation on the output of the hull mounted speed transducer, was deemed to be sufficiently accurate for normal steady-state data of Figure 14, it was found that a height change of approximately 3 feet, equivalent to a 1.4 knot speed error at 20 knots, occurred at takeoff. It was possible to apply this correction in the case of the minimum power takeoff. A similar correction could not be applied in the case of the continually changing normal and zero flap takeoffs.

CALM WATER TURNING

Spiral Turning

Dieudonne spiral turns were used to determine the hullborne and foilborne steady state turning characteristics of the RHS 200 in the heavy ship configuration. These trials also provide evaluation of the directional stability of the ship.

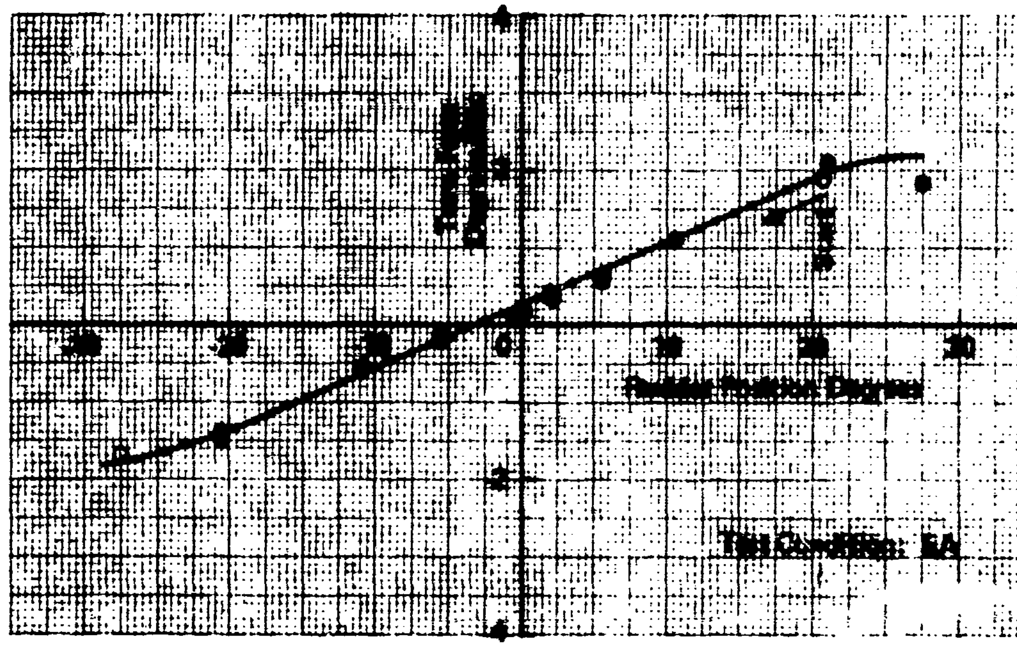
The trials were conducted by establishing straightaway operation of the required speed. The helm was then laid over to position the rudder at 20 degrees

right and held until a steady turn rate was established. The helm was then successively reduced to position the rudder at 10, 5, and 2 degrees right allowing turn rate to stabilize at each point. After zeroing the rudder and taking data at that position the rudder was then advanced left to 2, 5, 10, 20, degrees and full left positions. The entire sequence was then reversed, taking steady turn data at all intervals, until a full right rudder position was reached.

The results of the hullborne spiral turning tests are given in Figure 21. The hullborne turning characteristics of the RHS 200 are very nearly linear over the installed range of the rudder. There is some indication of a limit of rudder effectiveness at full rudder in the 10 knot data. Turn data is limited to approximately 2 degrees per second in that case. The 16 knot data display linear rudder effectiveness to full rudder where turn rates of 3 degrees per second were realized. This improvement in turning capability with speed was also evident in data obtained during the hullborne tactical diameter trials.

The data of Figure 21 are largely continuous through the near zero rudder position indicating that the RHS 200 is highly stable in the hullborne mode. The data of the figure indicates that a 2.5 degrees left rudder command may be required to maintain a straight course. Although this discrepancy was observed on the bridge during operation of the ship, it is noted that the signal used to drive the bridge rudder position indicator was also recorded by the data system. End-to-end calibration of rudder position was not possible so the data signal was calibrated to the bridge display. Therefore, it is not known if the rudder offset is actual or is a result of instrumentation inaccuracy.

The results of the foilborne spiral turning trials are given in Figure 22. The data for an initial speed of 28 knots are reasonably linear at or above nominal rudder positions of 5 degrees. The data for the higher speed case generally show the same trends except that more data scatter is present. Both sets of data show a clear lack of continuity between the right and the left turns where directional stability is marginal. These areas were evident while underway with the ship foilborne. During straightaway transit, minor helm corrections were input on an essentially continuous basis. There is no indication of a reversal of directional stability within the area of discontinuity. As fas as could be determined by observation, the ship always responded readily in the direction of



SPIRAL TURNING AT 10 KNOTS

← o Right to Left Rudder Sequence

• Left to Right Rudder Sequence →

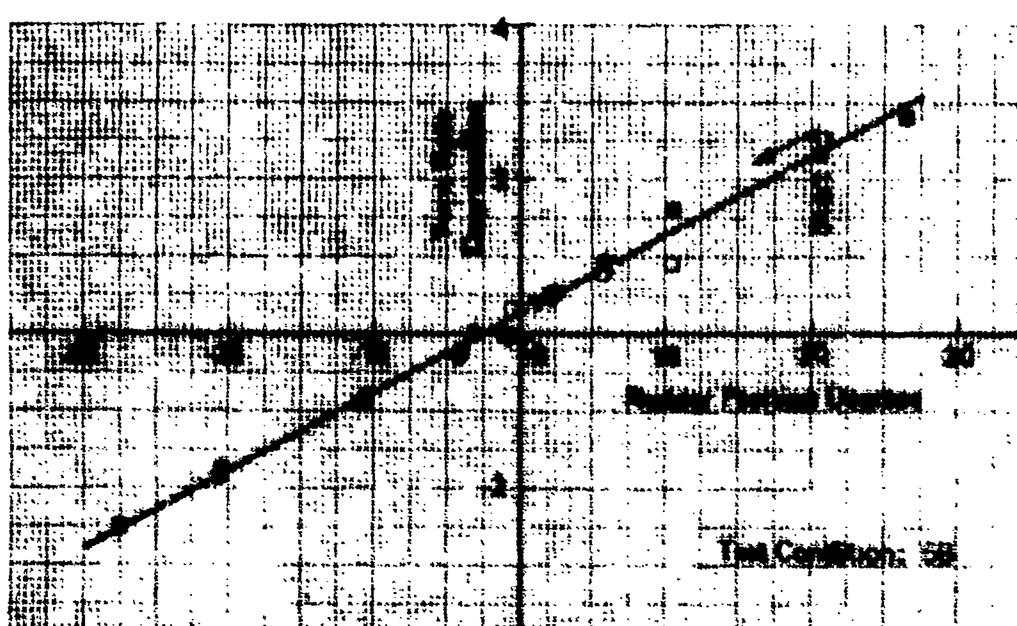


Figure 21 - Hullborne Spiral Turning at 10 and 16 Knots

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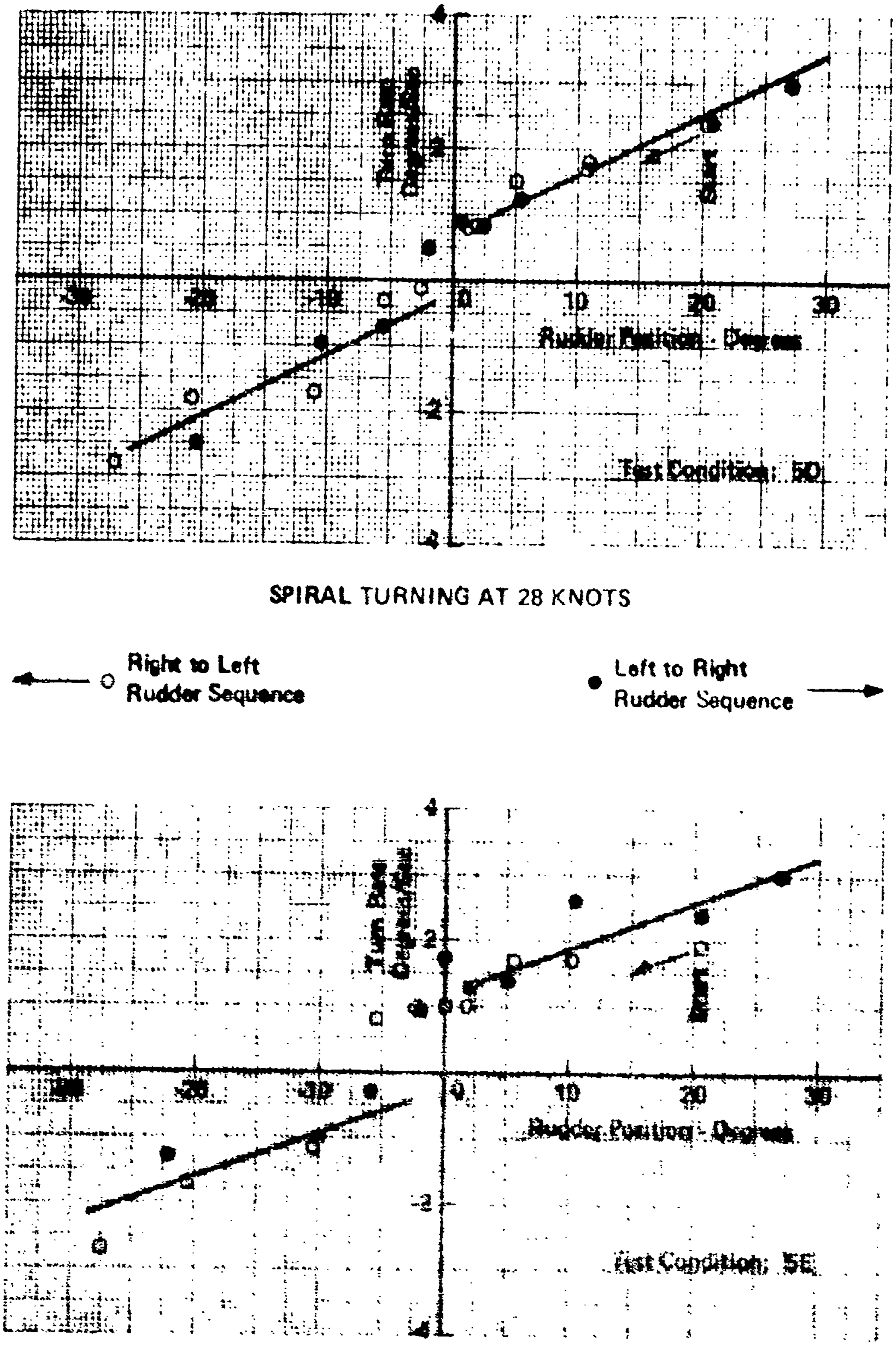

Figure 22 – Foilborne Spiral Turning at [illegible] and 35 Knots

the helm command. The region of marginal stability may result from flow or free surface disturbances on the more vertical, surface-piercing, sections of the foil systems.

Both sets of data in Figure 22 are positioned vertically in the plots in a manner which indicates that the ship may turn to the right more readily than to the left. This conclusion could not be supported in the data obtained from the tactical diameter or the debris avoidance turning trials. In the case of the spiral turns, the average yaw rate correction factor as discussed in the section on Data Reduction may not be sufficiently accurate enough for the case at hand.

The effect of turning on ship speed as defined from the spiral turning tests is given in Figure 23. A speed reduction of 15 percent occurs with full rudder commands while hullborne. The reductions appear more severe in the case of the foilborne data. Except for the relative low loss in speed indicated for the 35 knot turn data, the remainder of the foilborne data are consistent with actual occurrences. Foilborne turning maneuvers exert rather large drag forces on the ship at the higher rudder positions. It was later determined that, in the normal trim configuration, the ship would not remain foilborne with 20 degree rudder commands at speed over 30 knots.

Tactical Diameters

The USCG specification of Reference (3) requested a wide scope of hullborne and foilborne tactical diameter trials. The trials agenda consequently included plans for the conduct of 30 such maneuvers. Eventually, in excess of 22 tactical diameter trials were attempted or completed. Table 8 defines the scope of the completed tests. All of the noted turns were completed in both the right and left turn directions.

TABLE 8 - TACTICAL DIAMETER TRIALS COMPLETION

RUDDER POSITION, DEGREES	SHIP SPEED, KNOTS				
	8	12	16	28	35
10			X	X	X
15				X	X
20			X	X	X
FULL	X	X	X		

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

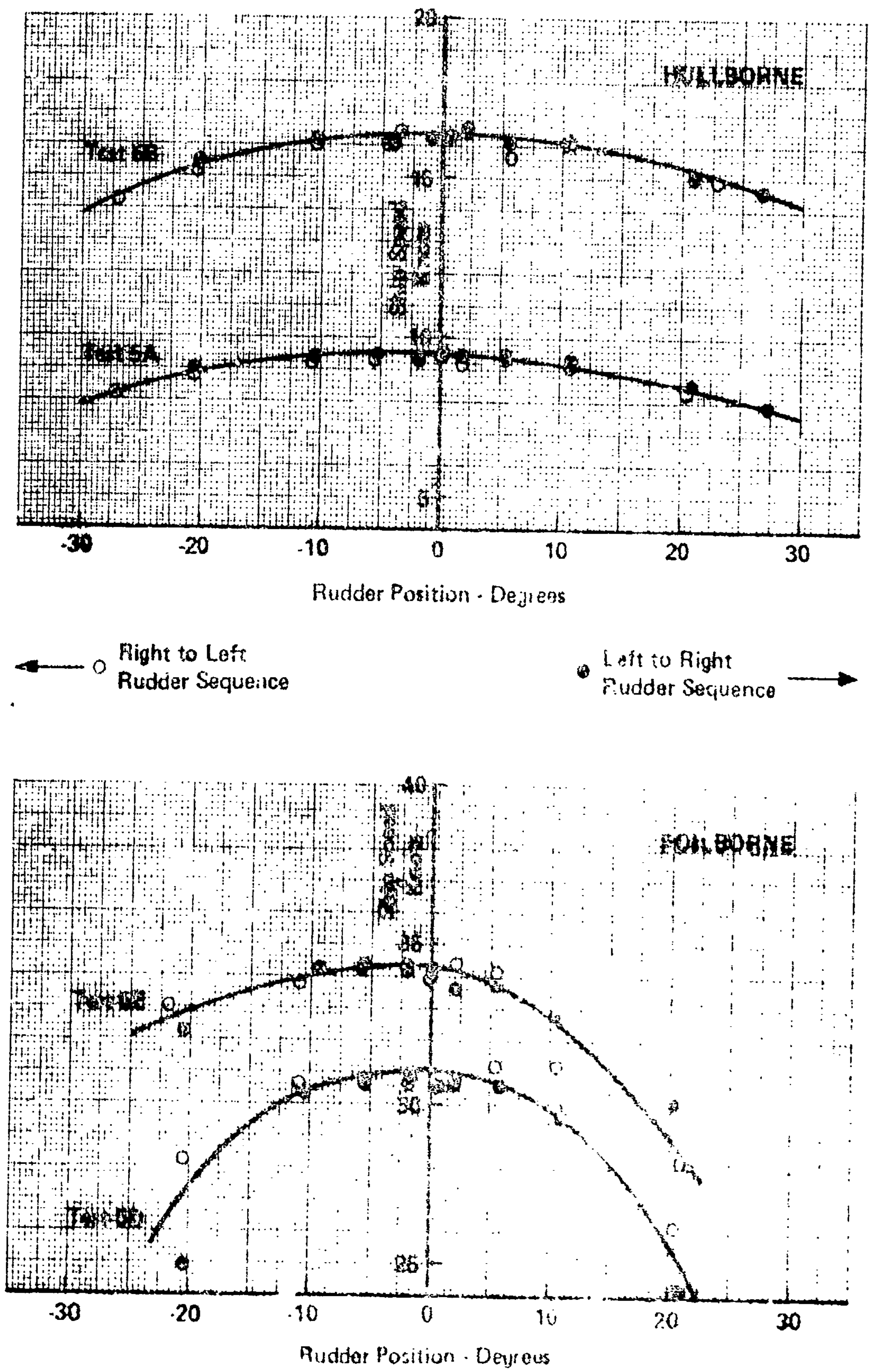

Figure 23 - Ship Speed During Spiral Turns

The tests were performed by establishing straightaway operation at required speed into the prevailing light seas. A "Condition On" event was noted and the helm was advanced to the required position. The rudder was held until a turn of 540 degrees was completed. The intervals required to complete each 90 degree quadrant within the turn and the length of the entire turn were timed. The bridge compass was used as the heading reference for conduct of the trials.

Full rudder foilborne turns could not be completed at either the 28 or 35 knot test speed. In addition, the initial attempts at conducting 35 knot tactical diameter turns at 20 degrees of rudder were not successful. These tests were cancelled when the after sections of the hull apparently contacted the water surface, initiating an increased drag situation which resulted in high engine loads. The 15 degree rudder tests included in the above table were selected in lieu of the 20 degree tests.

The 35 knot, 20 degree rudder, tactical diameter tests were successfully completed later in the test deployment. During these tests the SAS manual control capability was used to increase ship height and reduce trim thereby increasing aft hull clearance. The tests were conducted within convenient distance of a prominent headland and radar ranges to this point were used to confirm the tactical diameters. Average time and speed data recorded during the trials were used to estimate a tactical diameter of 870 yards at the same time that radar readings indicated a diameter of 800 yards.

The RHS 200 maintains very flat roll attitudes during turns. Roll angles were near zero during the 16 knot full rudder hullborne tactical diameter turns. During the 35 knot right turns with 20 degrees of rudder, the average roll angle was 2 degrees to the left. The Captain had expressed the opinion that the ship turned more readily if the SAS manual control was used to roll the ship into turns. Right and left turns at 35 knots with 15 degrees of rudder were made to investigate this possibility. In the case of the right turn, the starboard forward flap was set to 15 degrees trailing edge up, the port forward flap was set to 10 degrees down and the aft flaps were near zero. Similar, but reverse, flap positions were used to set up for the left turns. The rolled approach to the turns gave a physical feeling of improved turn capability, however, average time and heading change data taken from the bridge during the tests indicated that the

turn rates were at least 25 percent less than those obtained during normal turns. This type of turning was not investigated further and the limited data taken were not reduced in detail. Interactions between roll-created changes in foil system wetted area and panel effectiveness under turn-created side slip conditions could be postulated as reasons for reduction in turn capability. They cannot be presented with confidence without better definition of foil system geometry.

The individual tactical diameter trials were lengthy. The reduction of all data obtained could not be considered from a reasonable time and effort point of view. The data for 5 hullborne and 5 foilborne turns were processed and reviewed in detail. The final results justified the reduced effort approach. The RHS 200, as in the case of most hydrofoils, quickly entered into the turns and developed precise circular tracks. The trials data were initially reduced through TDAS definition of 2 second mean values of speed, yaw rate, and other turn-related parameters over the period of the 540 degree turn. These data were then computer integrated to define ship track through the turn. Separate yaw rate correction factors which were based on the timed 90 degrees changes in course were applied in each case.

A summary of the tactical diameter trials selected for data analysis is given in Table 9. In terms of minimum tactical diameter, the optimum way to turn the ship while either hullborne or foilborne would be to reduce speed and to apply maximum available rudder. This procedure would also provide minimum time-to-turn during foilborne operation. Minimum time-to-turn while hullborne would be achieved at the expense of increased diameter by increasing speed and setting full rudder. The average hullborne tactical diameter turn rates are in agreement with the turn rates developed in the spiral turns. This statement also applies to the 28 knot foilborne turn data. The 35 knot average tactical diameter turn rates indicate that maximum rudder effectiveness occurs with 10 degrees of deflection at that speed. There is little difference between the average turns rates which resulted with 10, 15 and 20 degree rudder commands at 35 knots. The average loss in speed during the turns of Table 9 was approximately 11 percent.

TABLE 9 - TACTICAL DIAMETER SUMMARY

NOMINAL SPEED Knots	RUDDER COMMAND Degrees	INITIAL SPEED Knots	SPEED IN TURN Knots	TURN RATE Deg/Sec	DIAMETER Yards
8	Full R	7.77	6.68	1.59	270
12	Full R	11.90	10.55	2.23	301
16	Full R	16.23	14.36	2.64	357
16	Full L	16.29	14.65	-2.67	342
16	20 R	16.21	15.09	2.27	429*
28	20 R	27.66	22.66	2.58	555
35	10 R	34.57	32.74	1.92	1102*
35	15 R	34.81	31.22	1.86	1082*
35	20 R	33.75	29.80	2.17	917
35	20 L	33.58	31.71	-2.16	919

*Based on average speeds and turn rates over 90 degree segments

Computer integrated traces of ship track during the hullborne tactical diameter tests are given in Figure 24. The starting point for the individual plots was taken at the time when the rudder was first deflected. The time interval between each successive data point is two seconds. A scheme using a closed symbol was adopted to signify the last 180 degrees of the complete 540 degree turn. In all of the cases within this figure ship advance into the turn does not lead transfer by significant amounts. The data indicates that in the worst case of 16 knots at full rudder, an advance of 200 yards was required before the transfer of 175 yards required to change heading 90 degrees was complete. Steady state turning conditions were achieved very early in the turns. The ship moved directly into, or immediately adjacent to its own wake as the first 360 degrees of turn was completed during a large majority of both the hullborne and foilborne tactical diameter trials.

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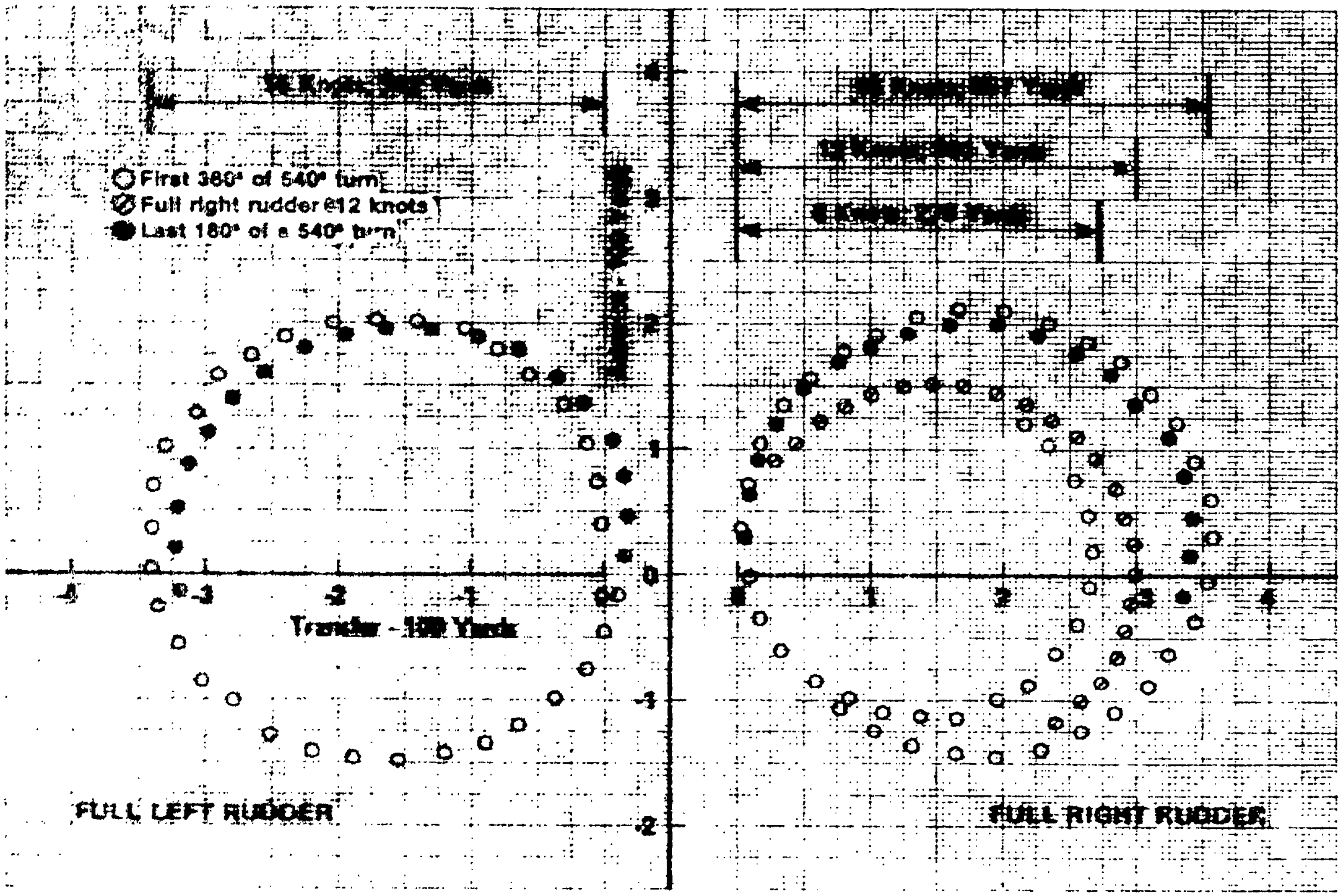

Figure 24 - Hullborne Tactical Diameters at Full Rudder

Ship track during 35 knot foilborne tactical diameter turns with 20 degrees of rudder are given in Figure 25. These data are for the special case where ship trim and height were adjusted to allow completion of the tests and track diameter was confirmed by radar. Both sets of data were obtained in near time frames and locales. The reasons for deviation in track in the case of the left turn are not known. Graphical representation of the effect of speed on foilborne tactical diameter is given in Figure 26.

Time dependent characteristics of tactical diameter turns at 16 knots with full rudder and at 35 knots with 20 degrees rudder are given in Figure 27. All of the data were developed over one second intervals. Some data points have been omitted for clarity. As stated earlier steady turn conditions are established quickly in the initial stages of the turn. Ship speed is essentially stable within less than 10 seconds.

Zig-Zag Maneuvers

Zig-zag maneuvers are used to evaluate the ability of the rudder(s) to control the ship. The following test procedures, which parallel those defined in Reference (6), were used in the RHS 200 trials.

1. Straightaway operation was established at required speed along a known base course.
2. The helm was rapidly advanced to the right to the required position and held until a course change of 20 degrees occurred.
3. The helm was then rapidly shifted and again held until a course change of 20 degrees to the left of the base course was achieved.
4. The helm was then shifted to the right at maximum rate and held until ship's heading was 20 degrees to the right of base course.
5. The helm was shifted left and the tests were ended as the ship approached a base course heading.

The zig-zag maneuvers were conducted at hullborne speeds of 8, 12 and 16 knots and at foilborne speeds of 28 and 35 knots. Rudder sequences of 10, and 20 degrees and full over were exercised at each speed. As in the case of the tactical diameter trials the data obtained exceeded reasonable data reduction time

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

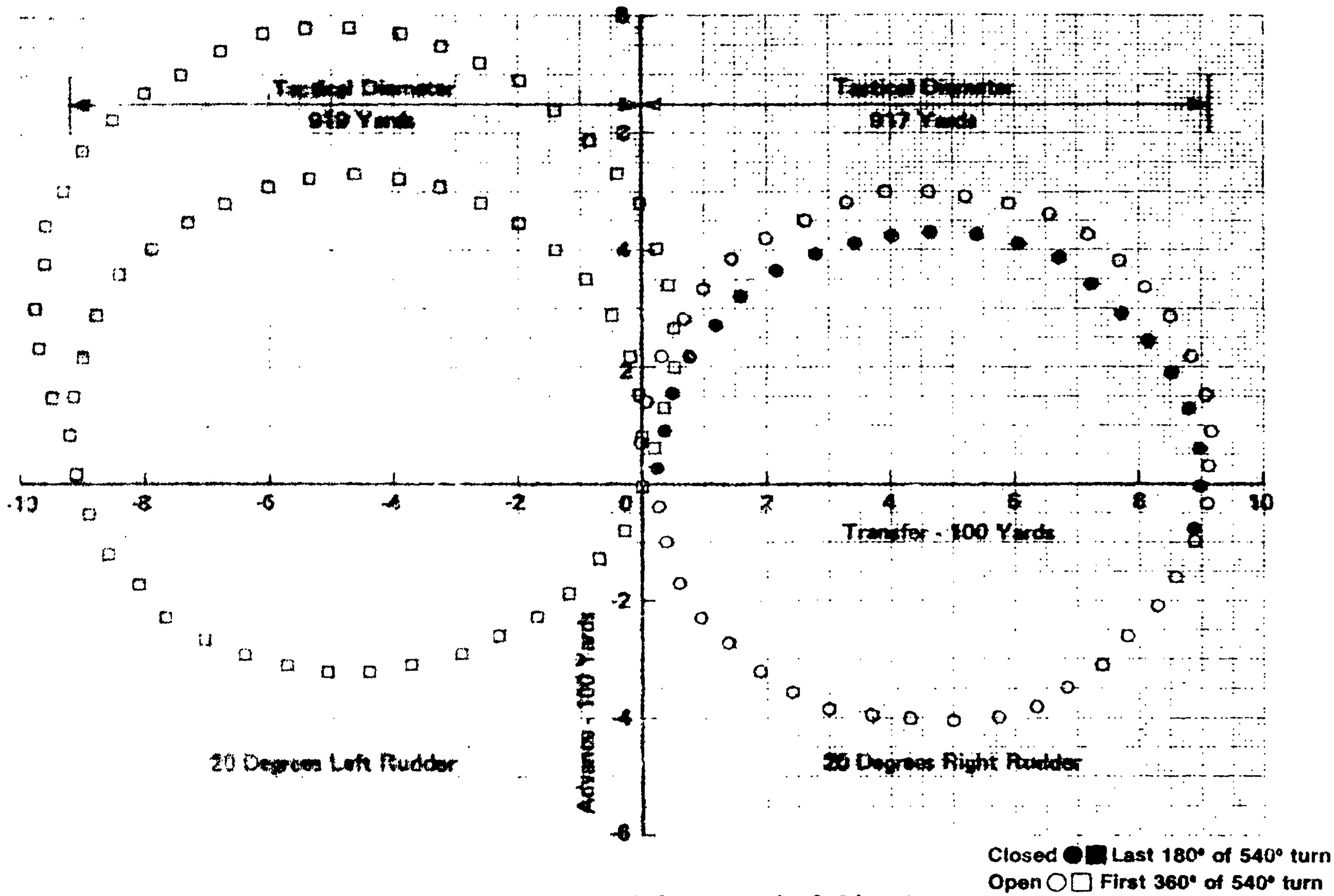

Figure 25 – 35 Knot Minimum Tactical Diameters

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

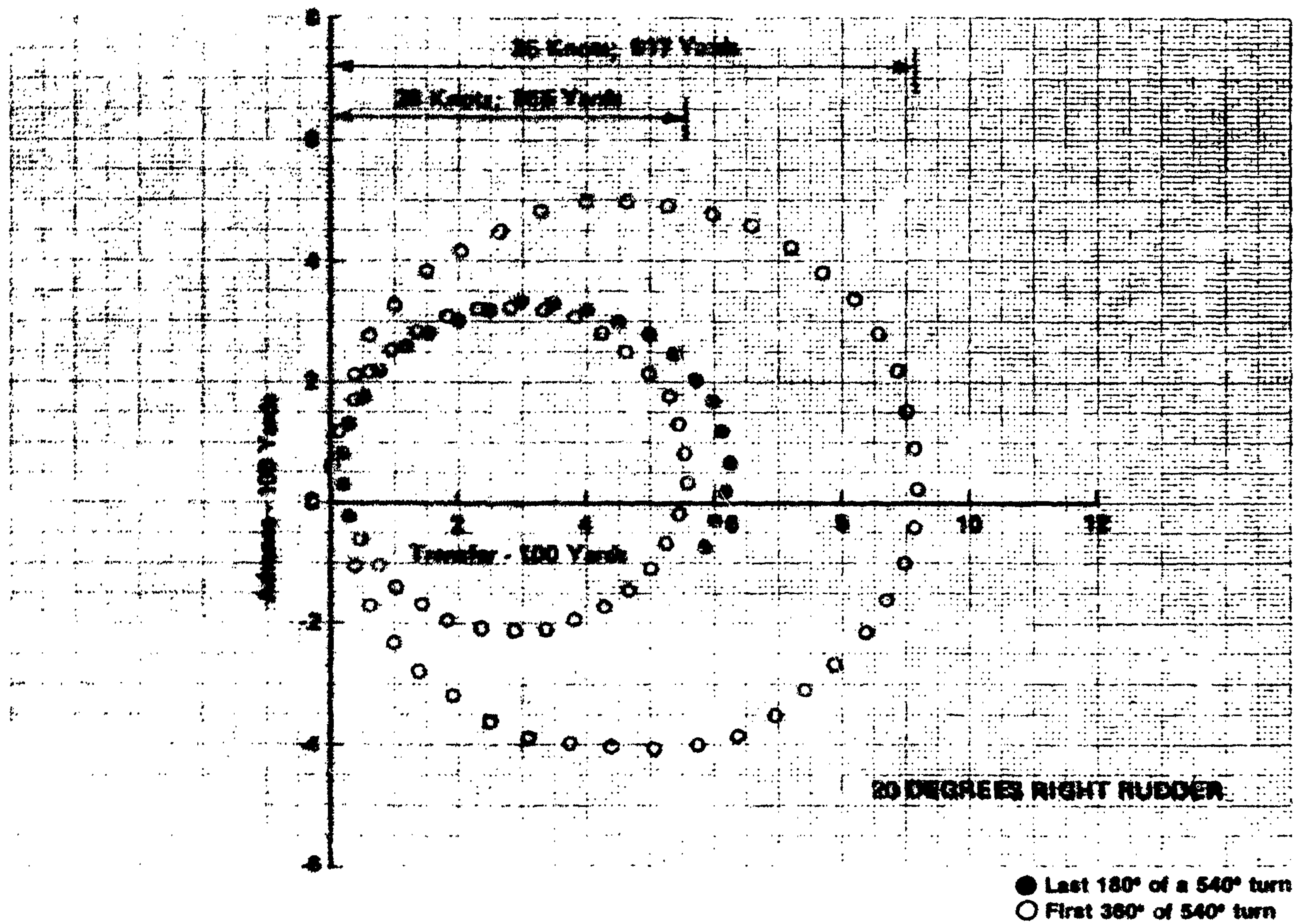

Figure 26 - Effect of Speed on Foilborne Tactical Diameter

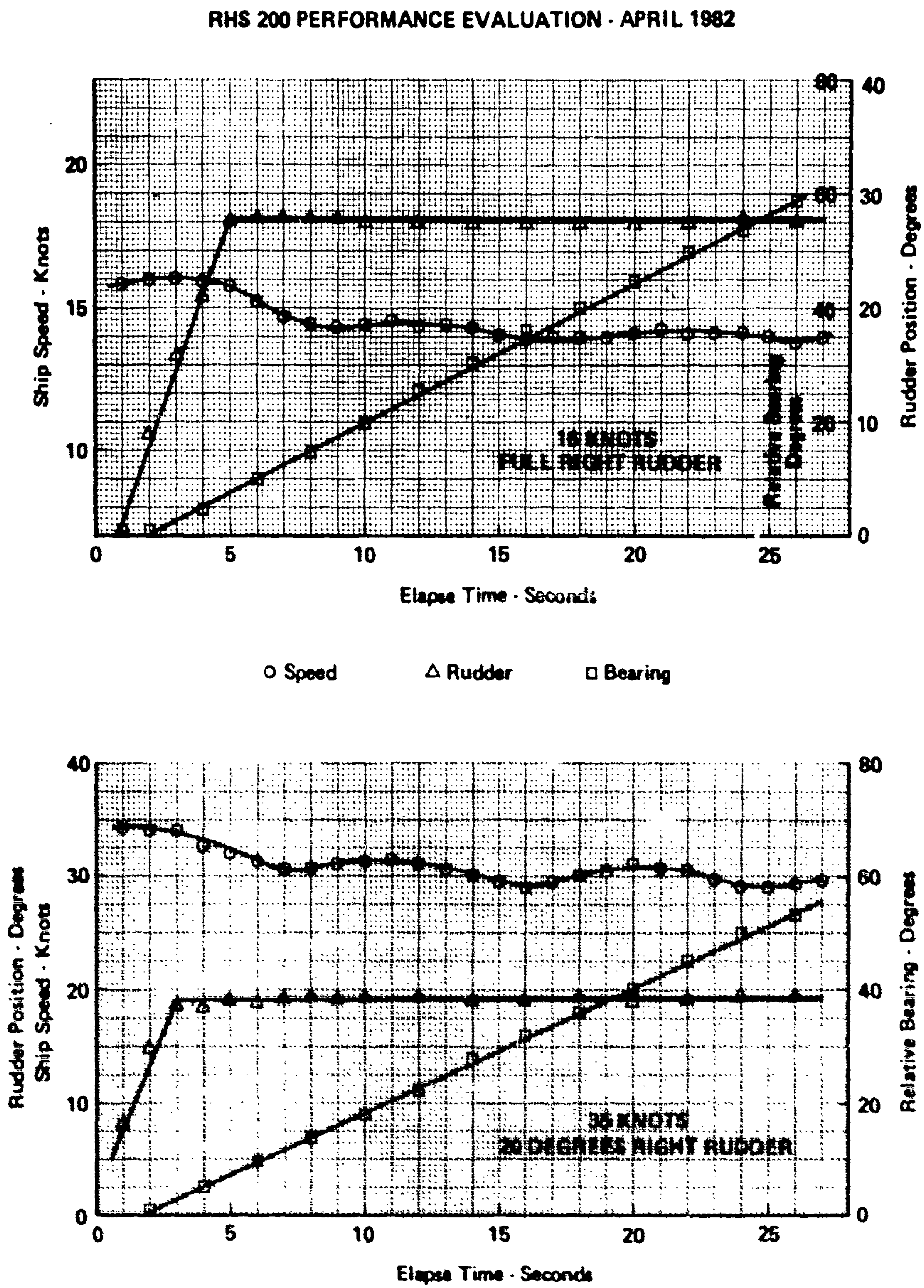

Figure 27 - Tactical Diameter Turn Development

and effort capability. Four tests were selected for detail presentation; 10 degrees of rudder at 10 knots, full rudder at 16 knots, 20 degrees of rudder at 35 knots, and full rudder at 35 knots.

The results for the selected zig-zag maneuvers tests are shown in Figures 28 through 31. The format of the presentations is that suggested under Reference (6). The rudder and yaw angle data have been plotted following the normal y-axis and right-hand rule positive sign conventions. A fictitious base course of 090 degrees was used in the computer integration of ship track to simplify data presentation. As a result, track displacement to the right of original track are plotted as negative values in the figures. The figures also contain supplementary information for use in resolving the non-dimensional ship length of travel along the track to dimensional units if desired. All of the information in the figures is based on one second analysis intervals. Numerous data points have been deleted to simplify the plotting process.

The primary results to be derived from the zig-zag tests include the time required to reach the first 20 degree change in heading from the straightaway condition, the overshoot in yaw angle which occurs after the rudder is reversed, and the overshoot in track which occurs before the ship returns to the original heading. The first result is a direct measure of the ability of the ship to change course rapidly. The other factors provide indication of the degree of anticipation which a helmsman must exercise while maneuvering in confined waters.

The zig-zag maneuver made at 16 knots with 10 degrees of rudder resulted in very low yaw angle overshoots and required a relatively long time, 20 seconds, to reach the first 20 degree change in course. In all three of the high rudder angle tests given in the accompanying figures the initial 20 degree change in course was completed in essentially 11 seconds. The overshoots in yaw angle were minimal, ranging from 7 degrees in the hullborne full rudder case to 2 degrees foilborne with full rudder. The overshoots in ship track were largely functions of speed. Those occurring in the 16 knot hullborne tests were essentially one-half of the 35 knot track overshoots.

Initial and average speed data are presented in the figures. In the 16 knot and the 35 knot 20 degree rudder tests the decay in speed was such that the

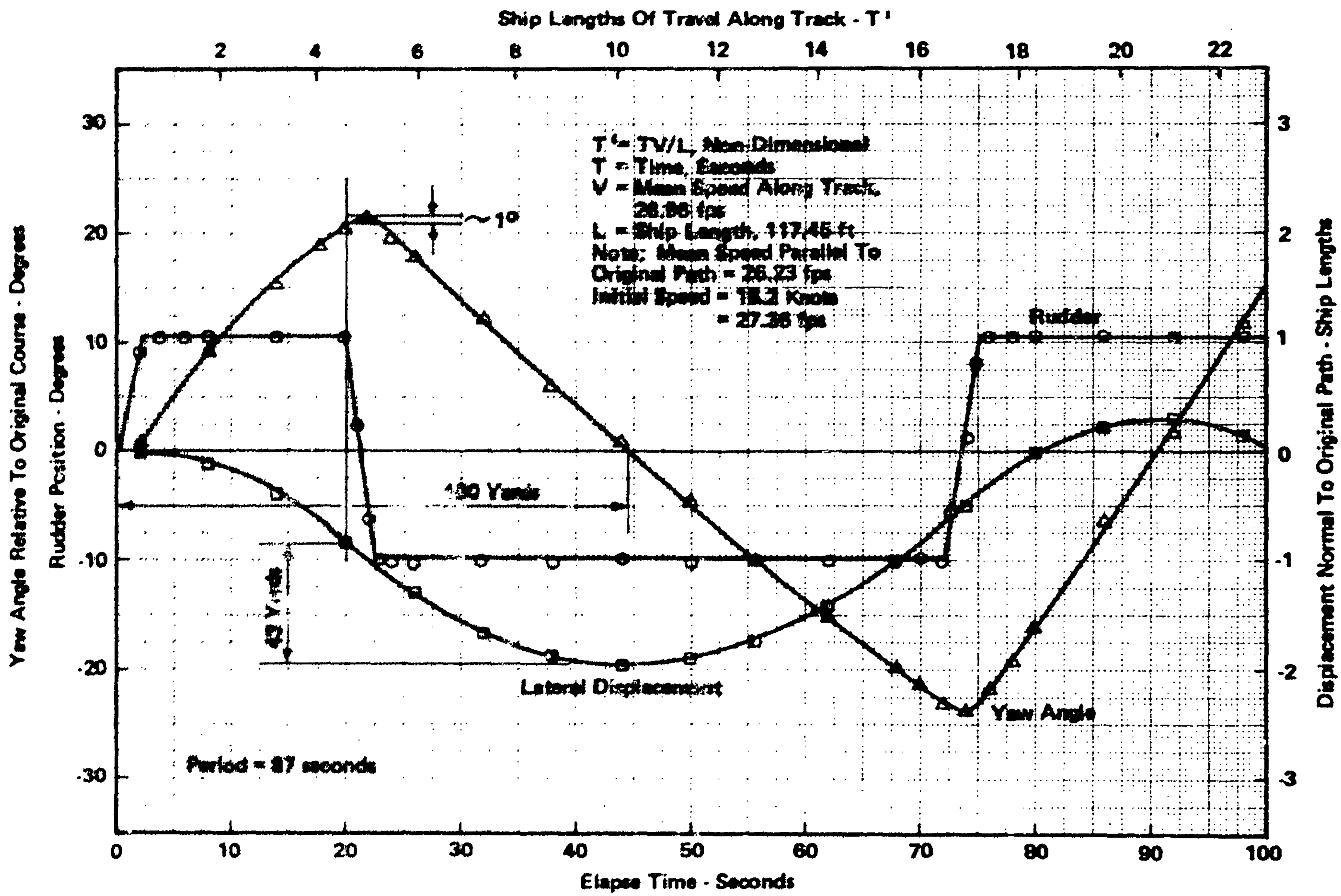

Figure 28 - Zig Zag Maneuver at 16 Knots With 10 Degrees of Rudder

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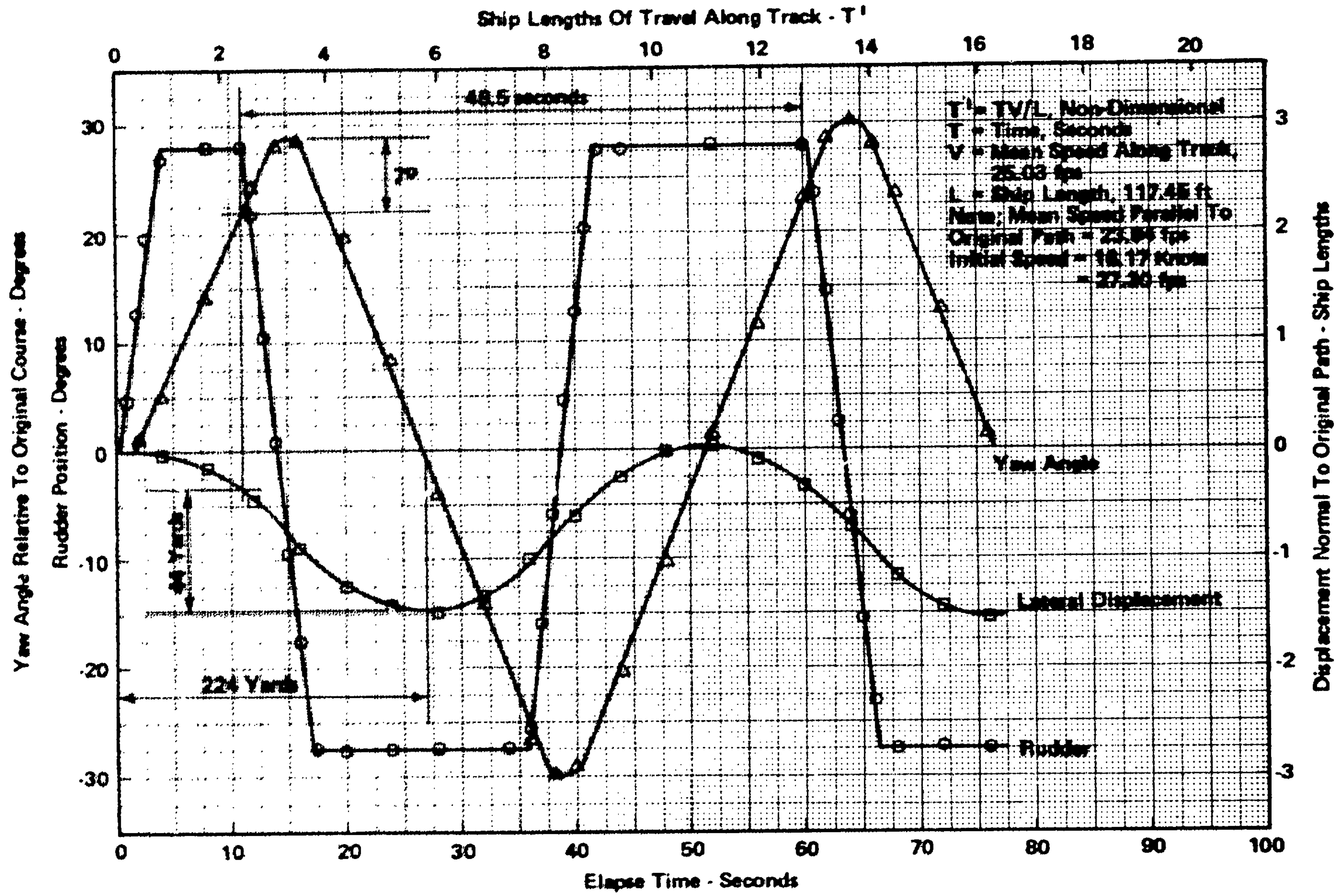


Figure 29 - Zig Zag Maneuver at 16 Knots With Full Rudder

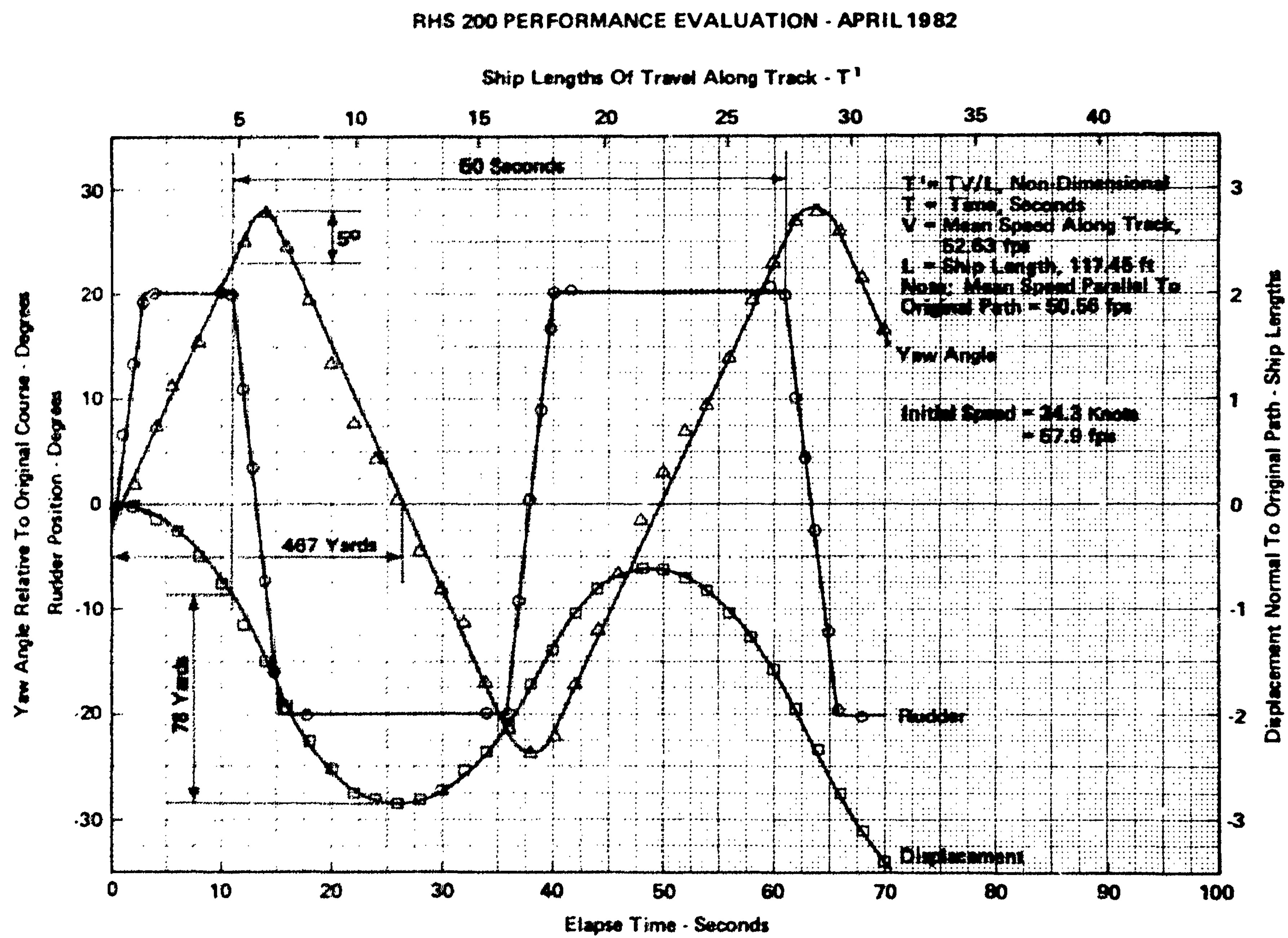


Figure 30 - Zig Zag Maneuver at 35 Knots With 20 Degrees of Rudder

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

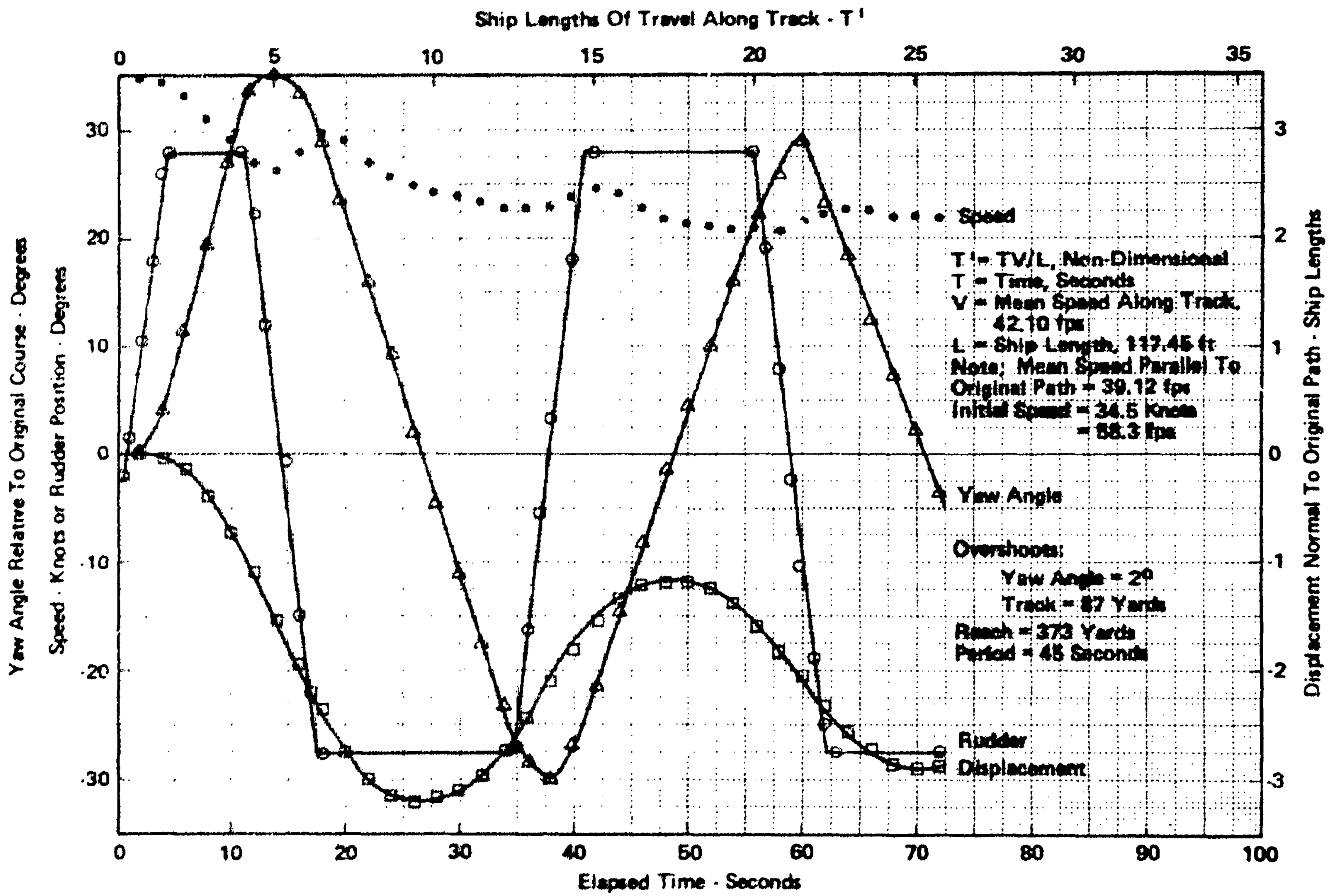


Figure 31 - Zig Zag Maneuver at 35 Knots With Full Rudder

given mean values were established within 19 seconds of the start of the test series. There was little need to include this information in the plots. The speed decay in the case of the 35 knot full rudder test series was much more severe and continued throughout the test. It is believed that the hull was dragging during parts of this test. If this contact occurred it did not have a noticeable effect on turn rate. The failure to return to zero track displacement during the last evolution of both of the foilborne cases is attributed primarily to the decay in speed. This discrepancy could also be influenced by inaccuracy in the measurement of yaw rate.

In view of the relatively small overshoot angles which occurred it is considered that the RHS 200 responded quickly and precisely to the rudder commands. The times required to reach the 20 degree course changes and the track overshoots which occurred are unfavorably influenced by the relatively low turning rates of the ship.

Low Speed Maneuverability

The investigation of the low speed maneuverability of the RHS 200 included the investigation of the minimum speed at which the ship would still respond to the rudders and demonstrations of ship turning while at zero speed of advance. The tests which investigated the limits of rudder effectiveness were conducted by setting straightaway operation at 5 knots speed into the prevailing light sea and then executing the following rudder schedule.

1. The rudder was advanced 10 degrees right and held for 30 seconds.
2. The rudder was shifted 10 degrees left and held for 30 seconds.
3. The helm was centered and initial conditions were re-established.
4. Steps (a) and (b) were repeated using full rudder commands.
5. Ship speed was reduced by 1 knot increments and the sequence repeated.

Under normal operating conditions idle speed of the RHS 200 is approximately 7 knots. In these tests idle operation of the engines was set and propeller pitch was reduced, independent of the combined throttle/pitch control, to set speed. During the tests speed was measured using a voltmeter installed on the

bridge which displayed the output of the speed transducer. The tests were discontinued when it became apparent the low voltages could no longer be read with confidence. The computer processed results of these tests are listed in Table 10. Rudder authority was maintained to a speed of less than 2 knots.

TABLE 10 - LOW SPEED MANEUVERABILITY

AVERAGE SHIP SPEED, KNOTS	AVERAGE RUDDER POSITION			
	10.8 Right	10.2 Left	27.8 Right	27.4 Left
4.76	0.67	-0.41	1.12	-1.17
3.32	0.42	-0.41	0.81	-0.89
1.81	0.21	-0.21	0.53	-0.55

Tabular values are turn rate, degrees/second

The zero speed turning demonstrations were performed using differential thrust to turn the ship. All aspects of the tests were under the control of the Chief Engineer who normally maintains throttle control during operation of the RHS 200. The combined throttle/pitch control levers were used to apply port and starboard, ahead and astern thrust as required to turn the ship and to maintain position. The test results are listed in Table 11. The thrust and power data have been included for interest purposes. It was possible to develop turn rates which were equivalent to those generated during underway operation of the ship.

It is emphasized that the data in Table 11 are for non-steady state conditions. The data are typical instantaneous values. The throttles required near continuous manipulation to avoid significant ahead or astern movement of the ship. None of the thrust or power information should be interpreted as representing the differentials required to achieve a specific turn rate while at zero speed.

TABLE 11 - ZERO SPEED TURNING CHARACTERISTICS

TURN RATE DEG/SEC		PROPULSION CONDITIONS			
		Engine RPM	Pitch Percent	Thrust Pounds	Power HP
0.57	Port	840	36	5,820	390
	Stbd	1,330	-79	-9,440	1,380
-0.51	Port	1,430	-83	-10,850	1,920
	Stbd	850	52	8,760	590
1.09	Port	923	36	10,030	720
	Stbd	1,320	-79	-9,930	1,530
-1.12	Port	1,430	-83	-10,640	1,935
	Stbd	960	60	14,640	1,090
2.03	Port	1,020	61	13,750	1,080
	Stbd	1,320	-79	-9,930	1,380
-2.18	Port	1,420	-83	-10,870	1,930
	Stbd	910	60	12,410	850

TOWING PERFORMANCE

Bollard Pull

The RHS 200 bollard pull tests were conducted with the ship secured by a stern rigged hawser to a mooring buoy. A DTNSRDC calibrated load cell was installed on the shipboard end of the hawser. A bridle arrangement was used to attach the load cell to lifting lugs installed on the afterdeck of the ship. Water depth under the ship was over 50 feet and the ship was in excess of 220 yards from the shore.

The tests were conducted at normal propeller pitch settings and at settings which were nominally 10 percent higher and lower than the normal values. In planning the tests it was intended to utilize engine speed settings from 800 to 1000 rpm in 50 rpm increments. Each rpm condition was set, conditions were allowed stabilize, and a data was then taken over a discrete interval. The normal pitch tests were limited to 950 rpm due to concern regarding the strength of the attachment point at the sea buoy. 980 rpm were set in the reduced pitch tests when the pull loads were lower. The increased pitch tests were limited to an engine speed of 900 rpm when it became apparent that the data being obtained did not differ significantly from the normal pitch data.

The results of the bollard pull tests are given in Figure 32. Propeller pitch varied from 35 to 60 percent during the normal tests and 30 to 50 percent in the reduced pitch tests. Engine power levels were well below maximum capability. As is noted these data are based on torque measured by the port torquemeter. The square of the ratio of starboard to port rpm was used to estimate starboard side torques during the tests. As noted in the Data Reduction section, the output of the port torquemeter was held to be questionable in other test instances.

Propeller shaft thrust as measured by the installed thrustmeter has been included in the figure. This data parallels the load cell data with the application of power. Shaft thrust is approximately 15 percent higher than measured pull at low power and 7 to 8 percent higher at the increased power levels. Thrust should only be 5 percent higher than pull if the thrust to drag conversions used to calculate propulsive efficiency in the Light and Heavy Ship Speed and Power section were correct.

Underway Towing Capability

The RHS 200 was used to tow a RHS 160 hydrofoil ship in the assessment of its underway towing capability. The RHS 160 class has a length slightly over 101 feet, a displacement of 85 tons and is configured for 160 to 200 passengers. The tests considered light and heavy towing conditions. In the light tow configuration both shafts of the RHS 160 were de-clutched and free to rotate. In the

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

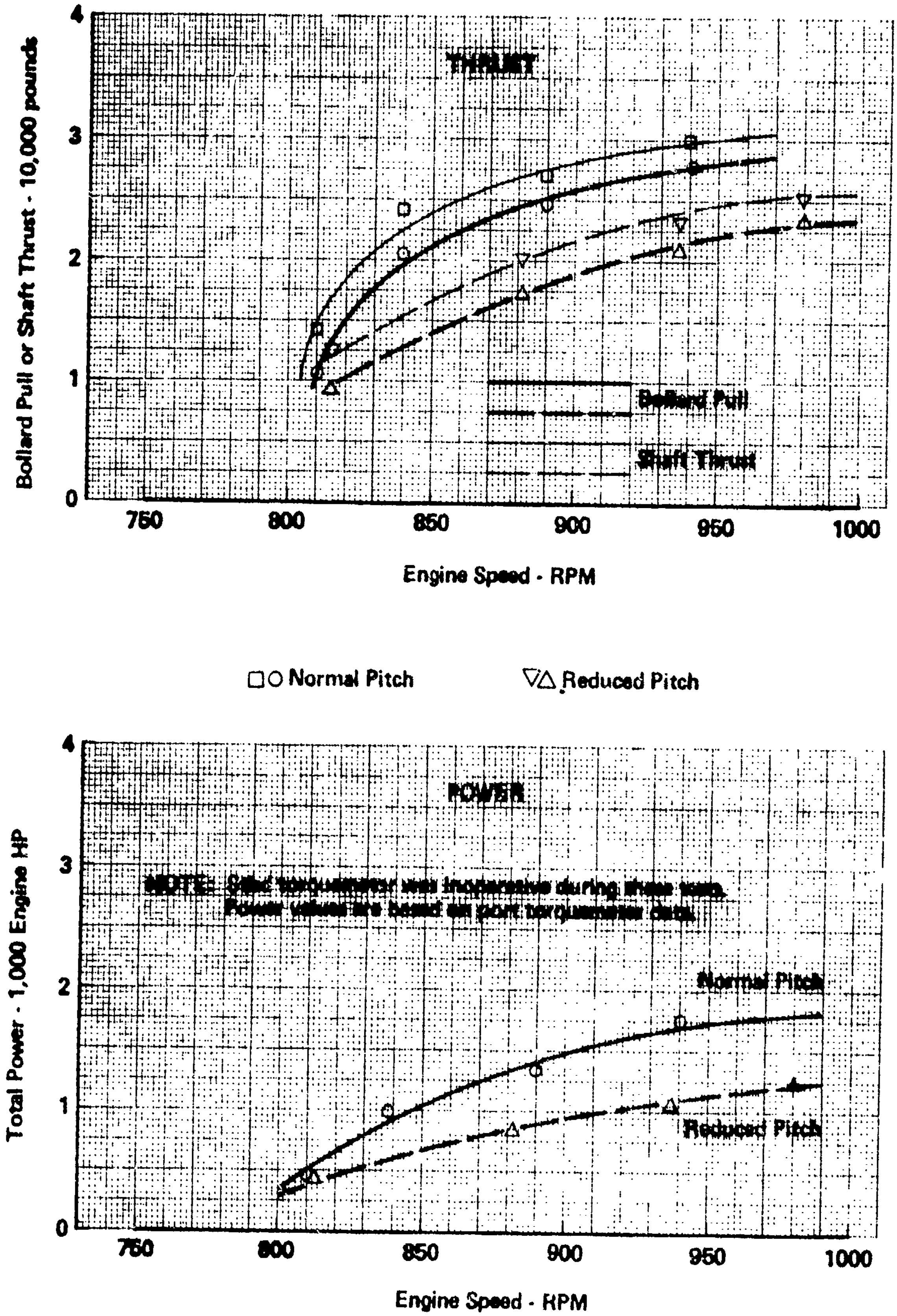


Figure 32 - Bollard Pull Capability

heavy tow configuration one of the RHS 160 shafts was free to rotate and the other was engaged in the astern position. Minimum power levels were maintained on the engaged shaft.

Both series of tests were performed by obtaining steady state data after setting straightaway operation at prescribed RHS 200 engine speed. The tests were initiated at an engine speed of 800 rpm, 100 rpm increments were applied up to engine maximum load capability. Engine load limit thresholds were typically defined by audible alarms at the engine status panels. The results of both test series are given in Figure 33. The light tow tests were engine load limited at an engine speed of 1260 rpm. At this time ship speed was in excess of 13 knots and a tow load of 16,000 pounds was developed. The engine load limit occurred at 1200 rpm under the heavy tow condition. In this instance a speed of 11 knots was achieved under a tow load of 17,000 pounds.

The effects of both reduced and increased propeller pitch were investigated with the light tow configuration. A 10 percent pitch reduction resulted in a loss in speed of 0.5 knots at 1200 engine rpm. Increased pitch yielded the same ship speed and tow force as the normal pitch tests but at a reduction in engine speed of 70 rpm.

RHS 200 Under Tow

The RHS 200 towing trials were conducted to determine its characteristics while under tow. Two test configurations were used. In the first test series both propeller shafts were free to rotate. In the second series the port propeller shaft was locked through the use of a locking bar installed between the propeller and the instrumented distance piece. The pitch of both propellers was set to near zero during both test series.

The RHS 160 was used as the towing vessel and the load cell was installed on its after deck between the hawser and deck mounted lifting lugs. The data system was maintained in place aboard the RHS 200. A voltmeter was used to monitor load cell output during the tests and the results were manually recorded. The bridge display of engine speed aboard the RHS 160 was used to control the tests. The range of speed available was determined during a pre-test power run-up. This information was used to define four test conditions 650, 700, 800, and

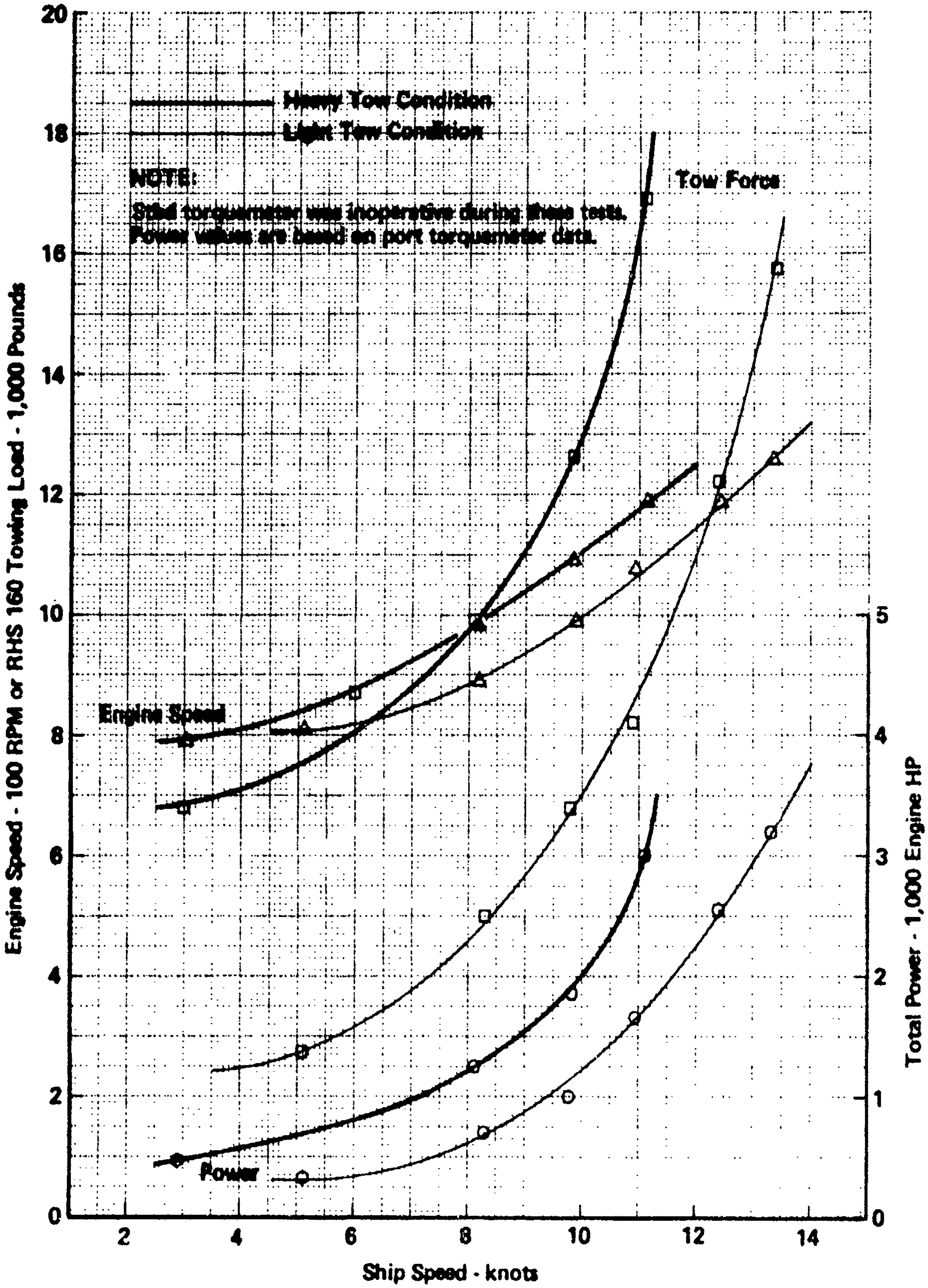


Figure 33 - Underway Towing Performance

900 rpm, to be set during the trials. The tests were conducted using procedures parallel to those used in towing of the RHS 160. The RHS 160 speed condition was set, conditions were allowed to stabilize and the required data was taken.

The results of the RHS 200 under tow tests are given in Figure 34. The tow force data were taken from the load cell output. Shaft thrusts were as measured from the RHS 200 installed instrumentation. The net drag curves, which should be and are essentially equal for both test cases, were defined by combining the tow force and the negative shaft thrust data. There are inconsistencies within either data set. Even at near zero propeller pitch settings, it was expected that the locked propeller would create drag forces which would be higher than the negative thrust forces generated by the propeller free to rotate. The starboard propeller should have generated the same negative thrust at the same speed in either test series. Starboard propeller pitch was typically 4 percent in both test series. The differences are insignificant. During the tests with the port shaft locked, starboard propeller rpm was between 270 to 400 rpm. In the second test series the rotational speed of each shaft was essentially constant, i.e., within 3 rpm of the noted averages. These shaft speeds are expressed in terms of propeller shaft instead of engine shaft rates as used elsewhere throughout this report. During the tests the engines were de-clutched and at idle.

The trim of the RHS 200 varied between 0.6 to 0.9 degrees bow up during the under tow tests. Attempts were made to use the SAS to retrim the ship during the tests at RHS 160 engine speeds of 800 rpm. The forward foil flaps were positioned up and down by 10 degrees. Ship trim was adjusted by no more than 0.2 degrees in either case and the effect on tow force was minor at best. The increased trim test data are plotted at a ship speeds of 9.7 and 8.9 knots respectively in the upper and lower sections of Figure 34.

ATTENDANT CHARACTERISTICS

Tactical Response

The tactical response tests included in the trials agenda were intended to provide actual demonstration of the time required to get the ship underway from a "cold iron" condition in response to a simulated emergency. The tests could not

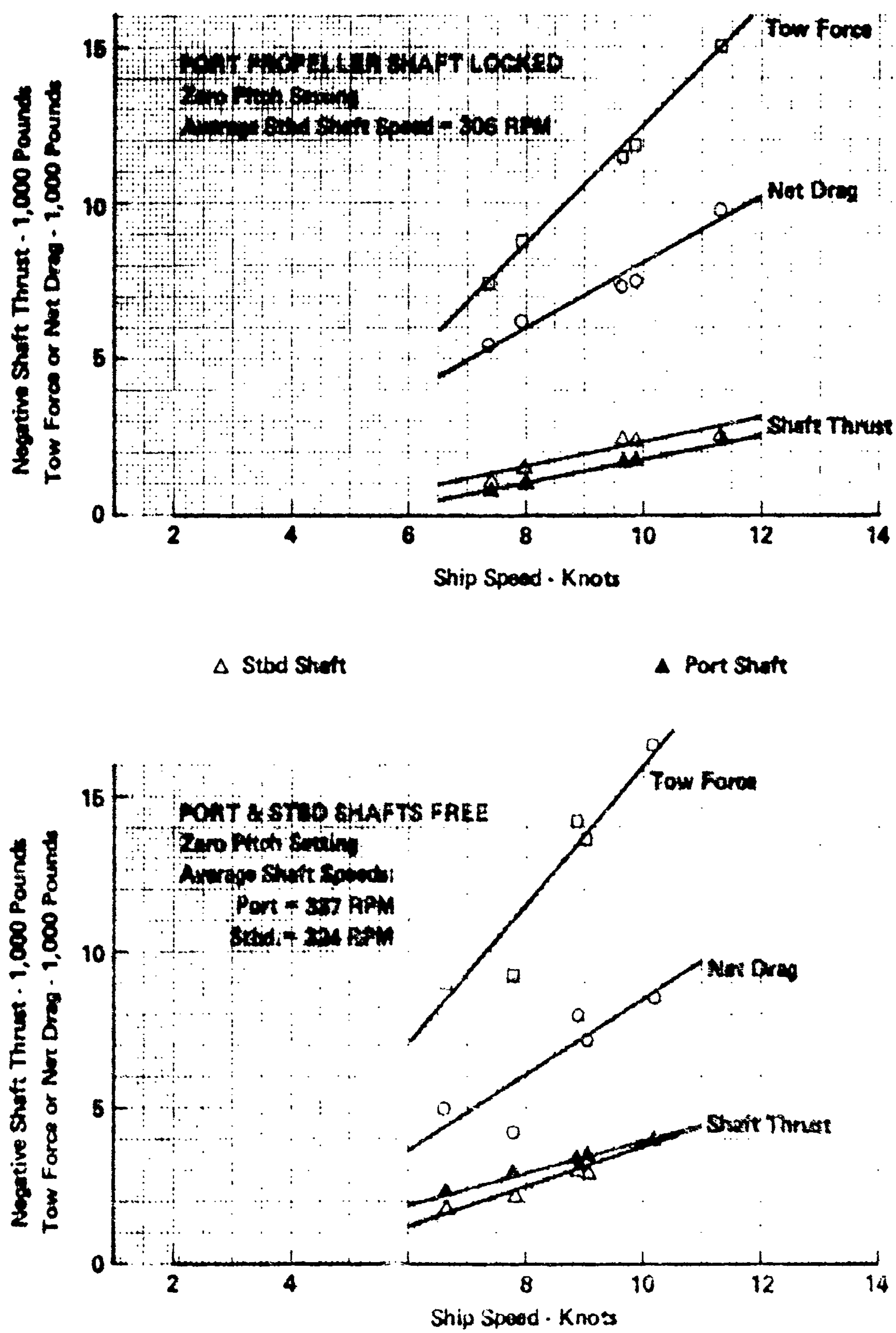


Figure 34 - RHS 200 Under Tow

be performed because the propulsion engines would be damaged if they were not adequately warmed-up prior to any departure. The minimum time required to get underway is dependent on the degree of engine damage which the operator is willing to incur. In lieu of testing, the time and the procedures required to get the ship underway in either a normal or an emergency situation were reviewed with the Chief Engineer. The results of these discussions are summarized in Table 12.

TABLE 12 - UNDERWAY RESPONSE TIMES

A. Normal Operation

1. Engine Warm-up to 45°C: 1-2 Hours; 18 - 6 kW @ Heaters
2. Complete All Other Activity During Warm-Up
3. Underway: 1 Min. at Idle for Reduction Gear Warm-Up
4. Foilborne: 1+ Hours From "Cold Iron"

B. Emergency Operation

1. Optimum Sequency or Simultaneous Activities:
    a. Check Fluid Levels
    b. Start Generator
    c. Circulate Pitch Control Oil
    d. Prime and Start Engines
    e. Set and Confirm Plant Control

    Estimated Elapsed Time: 5 Min.
2. Underway: 10 Min. at Idle for Reduction Gear Warm-Up
3. Foilborne: 15 Min. From "Cold Iron"

Some Engine Damage Will Result

Under normal operating conditions the engines are warmed up to a temperature of 45°C prior to getting underway. The ship is fitted with electrically-powered water heaters which are used to preheat engine cooling water. The time required to achieve starting temperatures is dependent on heater power levels.

Under a 6 kW load the preheat cycle requires 2 hours. This interval can be reduced to 1 hour under a 18 kW load. All other activity relative to aligning the engineering plant to operational status can be readily accomplished during the engine warm-up cycle. Although actual times would be dependent on ambient conditions at the start of the warm-up cycle, a minimum of 1 hour would be required prior to getting the RHS 200 away from the dock under normal conditions. The RHS 200 does not have the capability for preheating the reduction gearbox lubrication oil. Once the ship is underway, 10 minutes of operation at idle power is required to bring the gearboxes to suitable operating temperatures prior to operating hullborne at high power or to going foilborne. Approximately 1 hour and 10 minutes would be required to achieve foilborne operation from the "cold iron" condition if engine and gearbox damage is to be avoided.

During its initial period of service the RHS 200 was operated as a tourist passenger ferry during the summer months on the Mediterranean Sea. The ship was either underway or in an operational standby status between 0700 and 2100 hours. In those situations sufficient heat was retained in the engines so that next day warm-ups were not required.

The Chief Engineer of the RHS 200 was asked to outline the time and procedures which would be required to get the ship underway in an emergency situation where potential damage to the engines would have to be accepted. These activities are included in Section B of Table 12. It was estimated that they could be completed within 5 minutes. In this case foilborne operation could be set within fifteen minutes after receiving the order to get underway. The extent of engine damage which might be incurred could not be estimated. Referral to the engine manufacturer would be required before including "cold iron" operation as part of any emergency procedure.

Allowances for the time required to disconnect shore power, single up lines, or perform other deck related activity required for getting underway have not been included in the previous time estimates. During the course of the trials these activities were routinely accomplished within the five minutes required to bring the engineering plant on line under emergency conditions.

Crash Stop Response

The crash stop capability of the RHS 200 was evaluated for the cases where the ship was hullborne at 16 knots and foilborne at 35 knots. Each test sequence was completed twice. In the first sequence the Chief Engineer was requested to stop the ship as rapidly as possible. In the second sequence it was requested that the ship be brought to the full power astern condition. Although the actual conduct of the tests was straightforward, they were performed in a manner which made optimum use of the CP propellers. The initial conditions were set and, when advised, the Chief Engineer maintained engine power settings and manually reversed propeller pitch to stop the ship as rapidly as possible. Propeller pitch was reduced from the normal ahead position, typically 65 to 70 percent hullborne and 90 percent foilborne, to the full astern position in 3 to 4 seconds. As pitch was initially reduced, engine speed increased with reduced load to typically 1600 rpm. Engine speed was subsequently lowered as the reverse propeller loads were applied. It is believed that this procedure allowed more rapid application of full power astern than would have been available with fixed-pitch propulsion systems.

The results of the tests are listed in Table 13. The data have been developed from working plots used in the analysis of the data. The data intervals were initiated with the first indication of change in propeller pitch settings. The speed sensor was not active to zero speed. In all cases it was necessary to extrapolate speed versus elapsed time curves through the zero speed point. The deceleration of the ship quickly built-up to the nearly constant, average levels noted in the table. As a result, the speed-time relationship was very nearly linear and zero speed could be easily judged. This point was also used to identify end points within distance versus time plots. In the review of the foilborne tests a speed of 20 knots was arbitrarily selected as the time when the ship became hullborne.

The crash reversal tests yielded stopping distances which were slightly shorter than those which resulted from the crash stop tests. When hullborne at 16 knots it is possible to stop the ship in less than one ship length. A little more than three ship lengths are required to stop the ship from the 35 knot foilborne condition. The maximum load data marks peak astern power conditions.

TABLE 13. CRASH STOP RESPONSE

CONDITION		HULLBORNE		FOILBORNE	
Initial:	Speed, knots	16.3	16.7*	34	34.7
	Power	2550	2670	4100	4130
	Engine RPM	1150	1145	1455	1462
At 20 Knots:	Time, sec			6.5	7.4
	Distance, yds			98.8	96.4
Zero Speed:	Time, sec	8.8	8.0	12.5	12.3
	Distance, yds	42.3	30	125.5	120.2
Average Acceleration, g		-0.10	-0.11	-0.14	-0.15
Max Load:	Speed, knots	6.5	6.5	22	18
	Power, HP	3320	3400	3550	3530
	Engine, RPM	1390	1390	1390	1390
	Thrust, Lbs	-22500	-24300	-26480	-26170

* Crash astern tests

Wake Evaluation

A temporary, near-shore, data station was established for use in the measurement of the RHS 200 bow wake. Data station instrumentation consisted primarily of the DYNSPOT-HYSTUDET power conversion unit, wave height instrumentation strip chart recorder, and the data acquisition recorder. A portable diesel generator unit, provided by Rodriquez, was used as a power source. The height sensor antennas were mounted on a catwalk between two large pier blocks which were approximately [illegible] feet apart. The spacing was sufficient to permit most of the wave train to pass beneath the antennas before reflections, from the pier block

ahead of the train, disrupted further measurement. Water depth under the sensors was in excess of 30 feet. The measuring point was approximately 200 feet off-shore from a shallow-sloped, sand beach.

The tests were conducted by transiting past the shore station along courses parallel to the pier facility at offsets of 55 and 110 yards. The hullborne tests were limited to nominal test speeds of 10 and 16 knots. Foilborne speeds of 28 and 35 knots were used. Typical wave height traces obtained during these tests are given in Figure 35. The hullborne data included in the figure represent the heaviest wakes measured during the tests. In the 14 to 16 knot range, bow wave height is at or above 2 feet and has a period of 2.7 seconds. Foilborne wake was heaviest at the lower speed and was typically at or just below 2 feet. The periods of the foilborne wake traces in the figure are slightly below 2.5 seconds. The 27 knot wave trace at 55 yards is less well-defined than that of the 110 yard test. This is due to a deterioration of test conditions. The 55 yard foilborne tests were conducted late in the day when water conditions were becoming choppy.

Noise Measurements

Interior and exterior RHS 200 sound level measurements were obtained during the course of the trials. Broadband interior sound levels were recorded at various locations throughout the ship during the conduct of other trials. These data were obtained under both A and C weighting conditions. Rodriquez personnel recorded broadside airborne noise levels for the RHS 200 from the shore station during the wake evaluation trials. The results of the onboard measurements are listed in Table 14. No data were obtained for full power operation due to an oversight. A-weighted acoustic data implies progressively heavier attentuation of the measured signal as frequencies fall below 1000Hz. C weighted data is relatively unattentuated. Significant increases from A to C weighted sound levels implies that much of the sound energy is below 600 Hz.

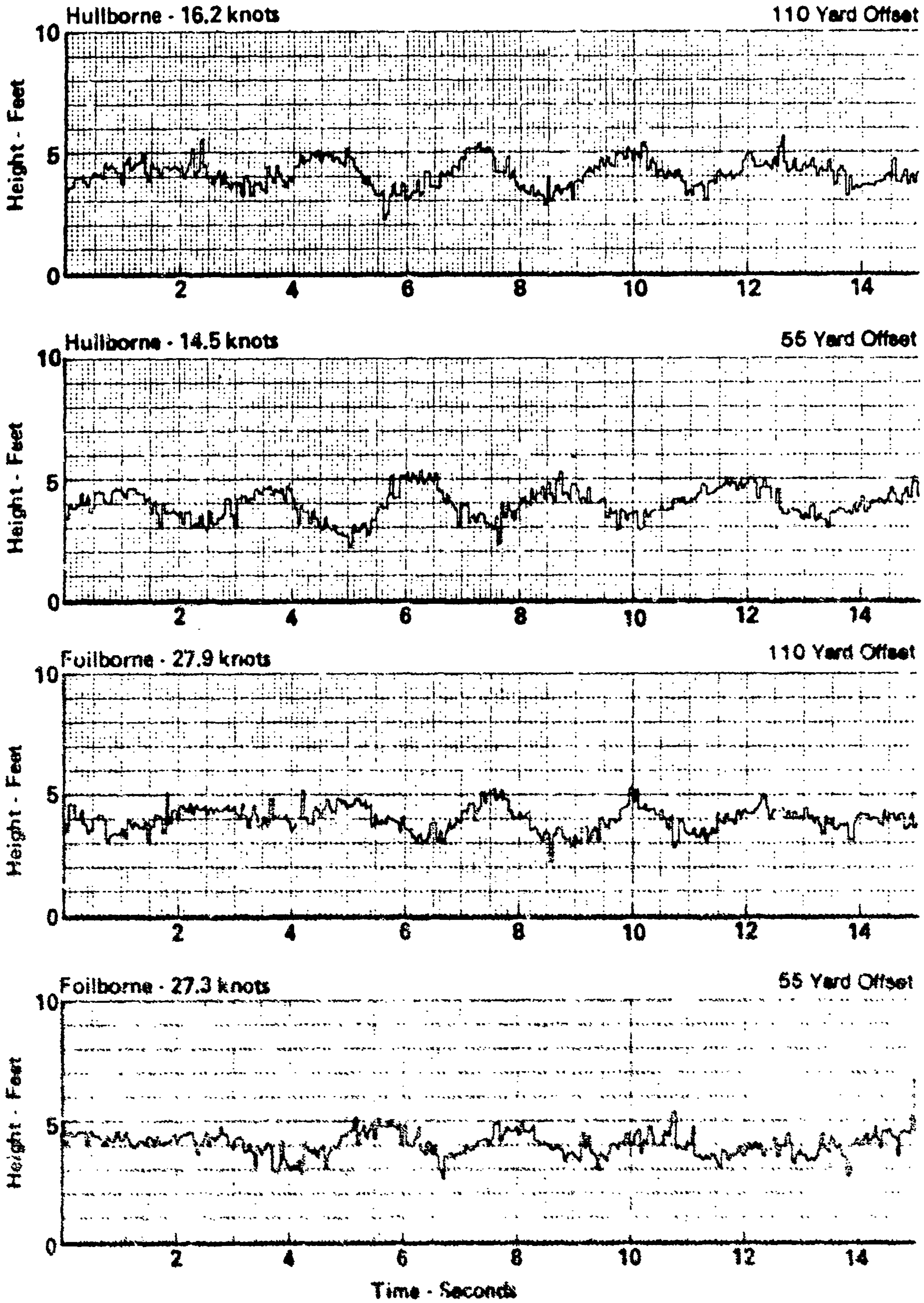


Figure 35 - Ship Wake Profiles

TABLE 14. AIRBORNE NOISE SURVEY RESULTS

LOCATION AND WEIGHT		10 Knots	16 Knots	28 Knots
1. Pilothouse	A Wgt	68	72	78
	C Wgt	88	93	97
2. Main Deck	A Wgt	70	73	78
Fwd Cabin	C Wgt	88	96	100
3. Main Deck	A Wgt	79	82	84
Stbd Passage	C Wgt	93	103	104
4. Main Deck	A Wgt	76	76	8[illegible]
Amidships	C Wgt	93	100	104
5. Main Deck	A Wgt	72	75	79
Aft Cabin	C Wgt	92	96	101
6. Lower Deck	A Wgt	71	71	80
Fwd Cabin	C Wgt	88	94	99
7. Lower Deck	A Wgt	72	76	82
Aft Cabin	C Wgt	69	96	101

*RMS dB Levels Relative to 20 Micro Pascal

The data of Table 14 should be addressed with caution. The RHS 200 is designed for passenger service and is normally well insulated and fully carpeted. In addition, a significant degree of sound absorption is usually provided by passenger furniture. The ship was not fully fitted out during these trials. All of the passenger seats were removed from the lower deck cabins. Most of the seating and all of the carpeting was removed from the main deck passenger areas. Hard-surfaced, plastic ballasting drums were also located in all passenger areas.

The most severe interior noise location was in the main deck starboard passageway. This area is immediately adjacent to the machinery space access trunk. The door to the trunk was held ajar to permit routing of instrumentation system cabling to the machinery space. Comparable measurements made at the port

passageway immediately adjacent to the main deck restroom yielded A-weighted dB (dB A) levels of 81 to 82. For evaluation purposes it is noted that Reference (8) requires the use of ear protection at or above 84 dB A. The threshold limit for an 8 hour exposure is 85 dB A. It is expected that if all furnishings and carpeting were installed on the RHS 200 in service all of the noise levels would be at comfortable limits.

Spectral definition of the exterior airborne noise measurements taken during the wake evaluation tests is given in Figure 36. The microphone was set up on one of the shore pier blocks and was situated where the peak noise values, which occurred as the ship was directly broadside, could be recorded. The data are essentially broadband and are a measure of noise broadcast by the unsilenced propulsion diesels. The engines exhaust outboard directly below the main deck amidships loading points which can be noted in Figure 2. The data of Figure 36 indicated that there is some reduction in noise with a reduction in power. The reduction in sound level pressure between the 110 yard and the 55 yard data sets is as expected. The differences are roughly proportional to the inverse square law. At the time of the tests Rodriquez personnel noted that exhaust silencers were fitted to some of their other hydrofoil ships in use in areas where noise limitations were in effect.

Structural Vibrations

The trials agenda specified that the vertical components of structural vibrations be measured at several different locations throughout the ship. Broadband and peak accelerations and displacement velocities were to be measured. All of the required data were obtained. However, Rodriquez used this opportunity to obtain more definitive data samples which were processed using spectral analysis. Copies of the spectral analysis results were provided to the DTNSRDC-HYSTUDET Trials Director. Although the spectral data did not cover as wide a range of ship speed conditions, and it was not obtained at as many locations as the broadband and peak data it is by far the most substantial of the data sets. Consequently, none of the broadband or peak data have been included in this report.

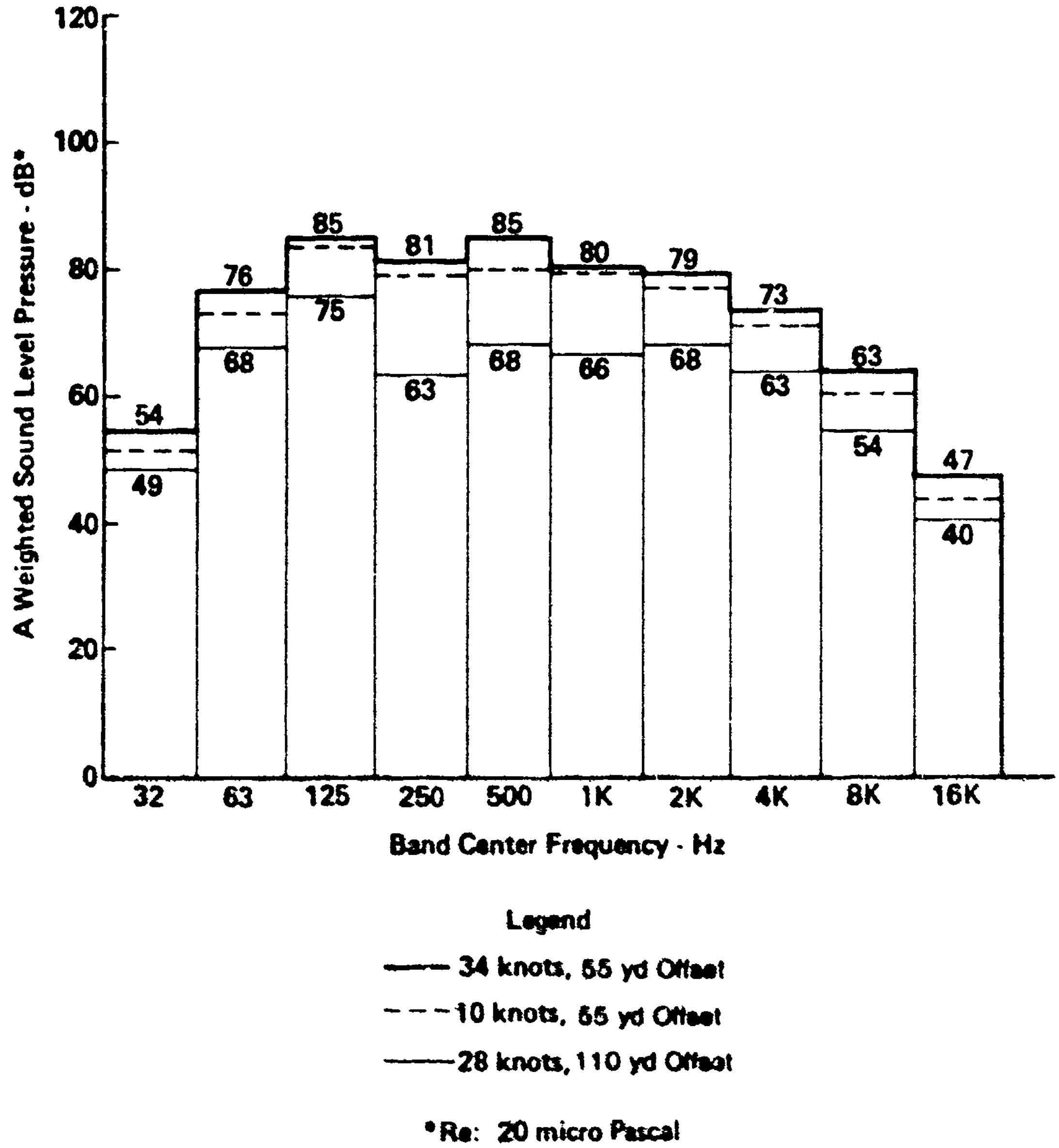


Figure 36 - Broadside Transmitted Sound Levels

The Rodriquez structural vibration data was obtained at the forward bulkhead of the forward lower cabin, near the CG at the instrumentation sensor package installed on the main deck, and at the after bulkhead of the after lower cabin. The acceleration measurements were made in the vertical direction and were taken at ferrous metal pads cemented to the deck as close as possible to structural members. The lower forward cabin was considered to be one of the most comfortable passenger areas. The main deck location was directly over the machinery space. The lower deck after cabin location was, in the passenger sense, in the closest proximity to the aft foil and the propellers. Vibration data was obtained at each of the positions at ship speeds of 16, 18 and 35 knots. Both engines were operating at, or very close to, the same speed during the measurements.

A sampling of the vibration data provided by Rodriquez is given in Figures 37 through 40. The included data are typical of all of the spectrum generated. As expected, the elements of the propulsion systems are the primary sources of the structural vibrations throughout the ship. The fundamental and second harmonics of the engine and propeller shafts and the propeller blades have been listed and identified within the figures used in interpretation of the data. The decibel scaling is based on International Standards Organization (ISO) standards. Under this system an acceleration level of 120 dB is roughly equal to 0.10g. 100 dB is by definition, approximately equal to 0.01g. The acceleration of gravity in the metric system of units is 980 cm/sec^2. It is noted that the U.S. Navy uses a different dB standard wherein an acceleration level of 120 dB is approximately equal to 1.0g.

The upper cabin vibration data given in Figures 37 and 38 provide a comparison of the differences to be found with changes in speed and in mode of operation. These data are also the most severe of that experienced throughout the ship. The spectral distributions can be evaluated from two points of view; the operating condition of the propulsion plants or the effects of the vibration on the human body. The use of the enclosed data for analysis of the propulsion system conditions would not be completely appropriate due to the fact that none of the measurements were taken directly on, or adjacent to, elements of the system. In Figure 37 the peak acceleration of 118 dB at 39 Hz, 2x engine shaft

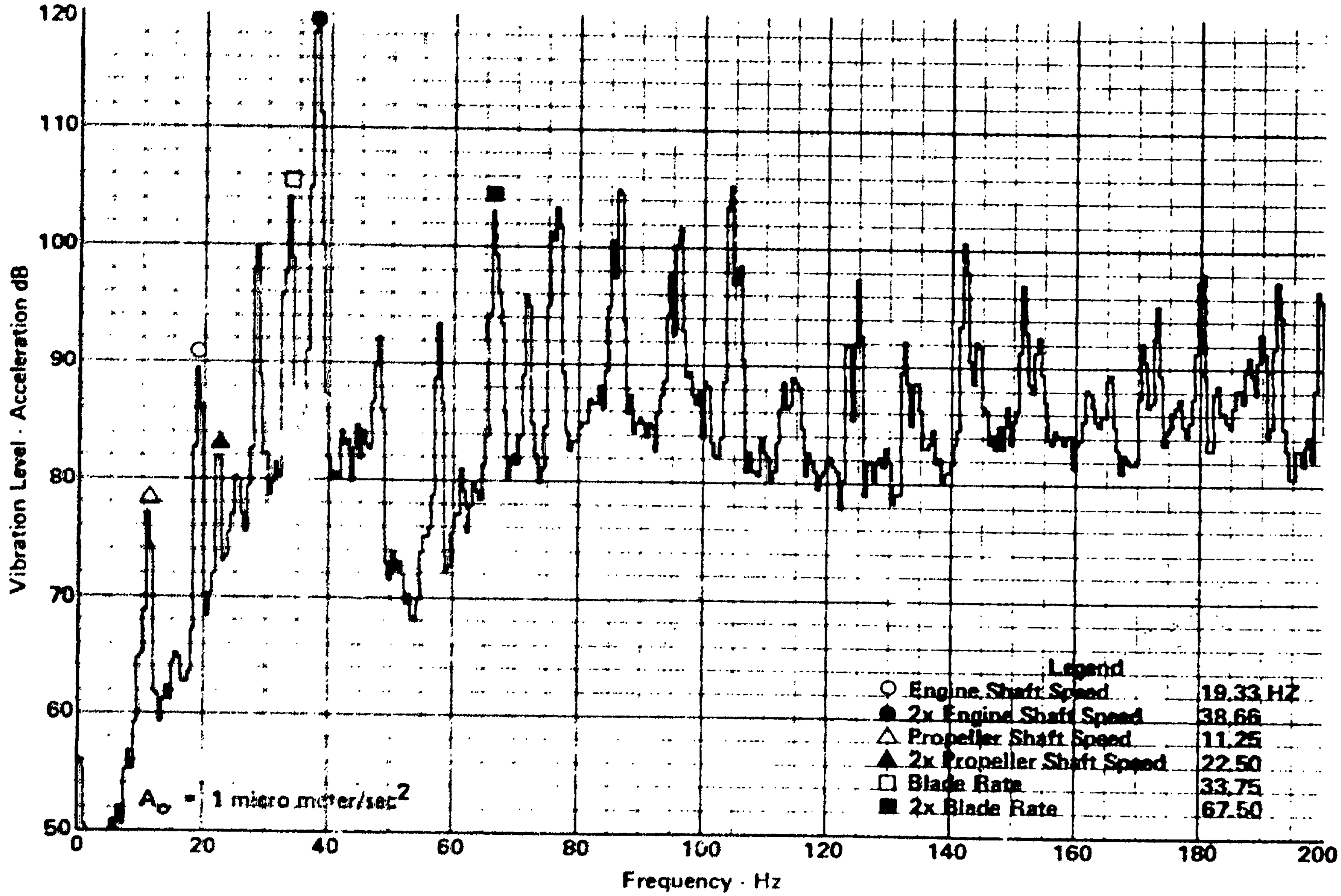


Figure 37 - Structural Vibration Spectrum: Upper Cabin at CG; 16 Knots

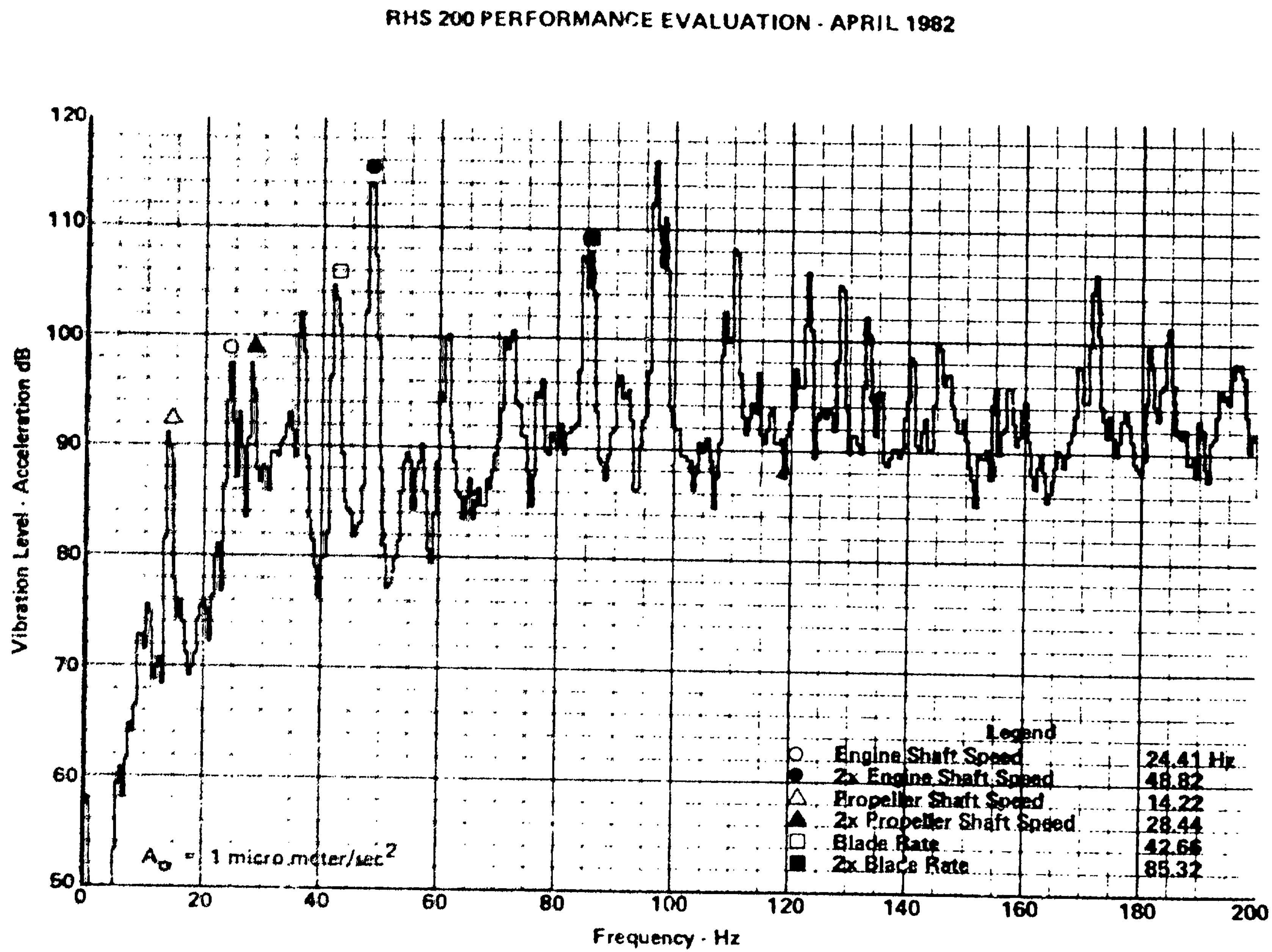


Figure 38 - Structural Vibration Spectrum: Upper Cabin at CG; 35 Knots

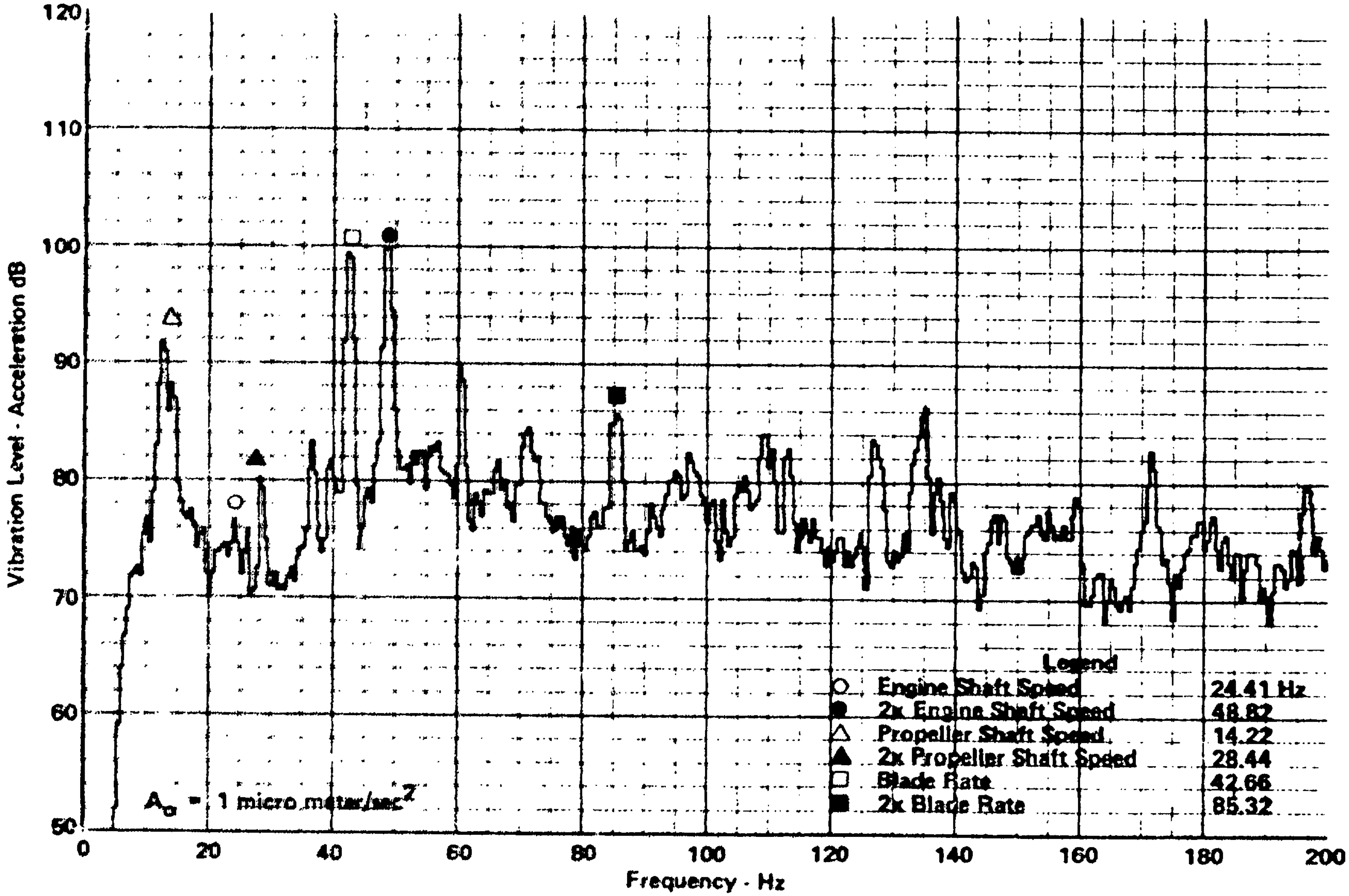


Figure 39 - Structural Vibration Spectrum: FWD Lower Cabin; 35 Knots

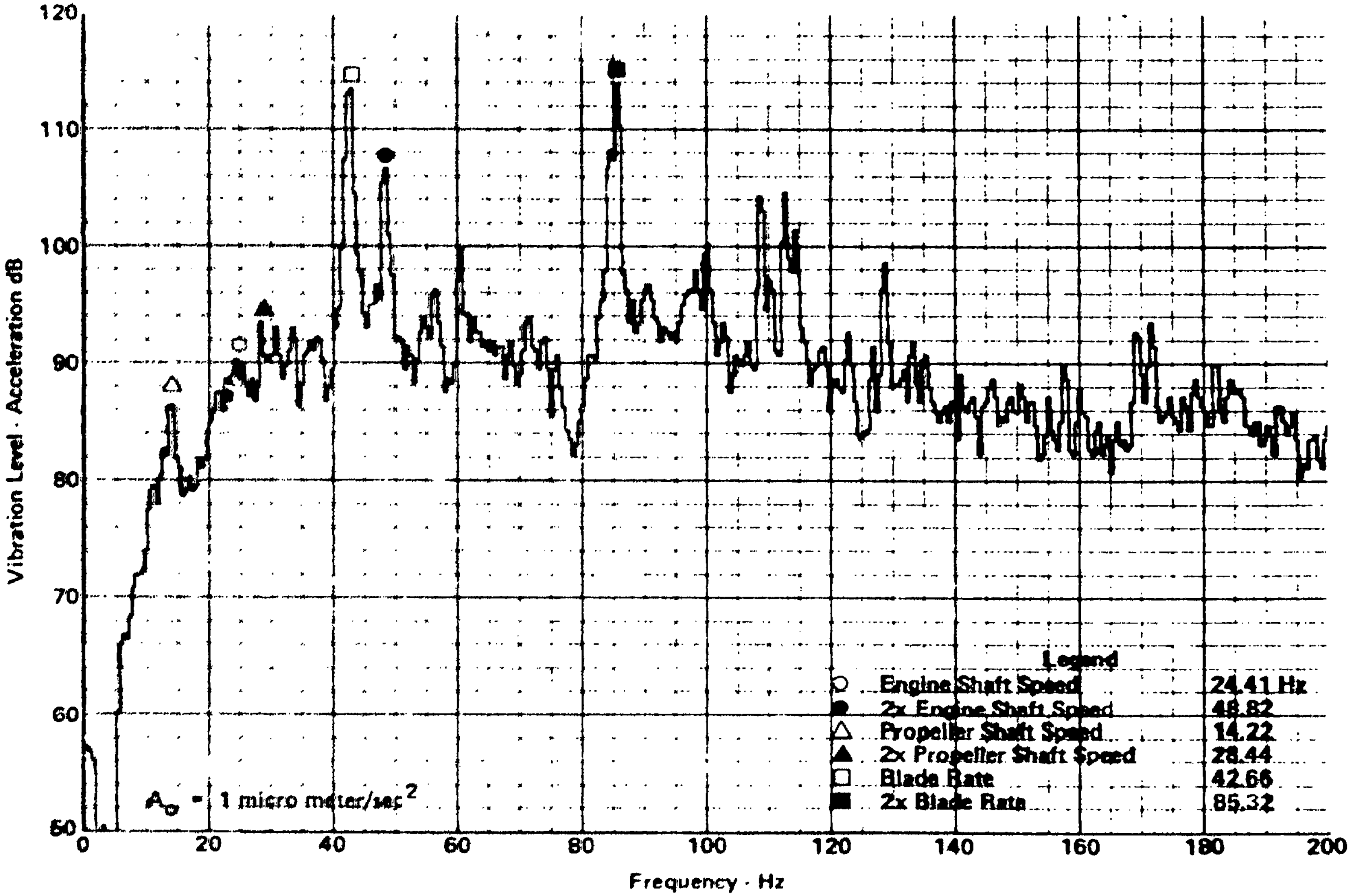


Figure 40 - Structural Vibration Spectrum: AFT Lower Cabin; 35 Knots

speed, is evidence of a slight misalignment of one or both of the output shafts from the engines. The level as measured on the main deck structure is within industrial boundaries for normal operation. The question exists, however, regarding the level of vibration which may be present at the shaft bearing supports.

In terms of human response, ISO Standard 2631-1978 on vibration exposure criteria as quoted in Reference (9), places 118 dB at 39 Hz to be within the 2.5 to 4 hour "reduced comfort boundary". Figure 38 indicates that the second harmonic of engine shaft speed is reduced in level to 114 dB. At this higher test speed its frequency is 49 Hz. With these changes the "reduced comfort boundary" is expanded to 8 hours. The ISO comfort boundary increases rapidly in time with increasing frequency. There are no other peak accelerations within Figures 37 and 38 which fall within ISO included boundaries.

The increased passenger comfort available within the forward cabin on the lower deck is clearly evident from the acceleration spectrum for 35 knots in Figure 39. It is interesting to note the clear presence of both propeller shaft and propeller blade rate frequencies in this data. All of these peaks are well outside of a ISO 24 hour "reduced comfort boundary". The lower-deck, aft cabin data for 35 knots included in Figure 40 show the closer positioning to the propellers. The 113 dB acceleration at blade rate frequency of 43 Hz is also at the 8 hour comfort boundary. For information purposes it is noted that vibration excitations at propeller blade rate are most likely the result of loading and unloading of the individual blades with each rotation of the angled shafts. Blade rate excitations could also results from the flow field, or downwash, of the aft foils entering into the propeller disc areas.

ROUGH WATER PERFORMANCE EVALUATION

TEST CONDITIONS

Scope of Tests

A wide selection of rough water trials were planned in the RHS 200 performance evaluation. As is often the case, they could not be performed because of limited rough water availability. After the completion of essentially all calm water testing it was apparent that contract funding would expire before any rough water tests could be performed if they were not initiated in a near time frame. At this time Rodriquez proposed the interruption of the lease agreement until such time that the testing could be undertaken. The proposal was accepted and a standdown period which ultimately lasted for four days was entered. On 8 May 1982, rough water conditions were reported both to the north and the south of the Straits of Messina. A deployment to the south of the straits was made where sea conditions, visually estimated to be State 3, were found and testing was initiated. Later in the day, a transit was made to the north of the straits where, again based on visual estimates, State 4 sea conditions were present and further trials were conducted. A second rough water trials deployment was made on 9 May 1982 when additional State 3 trials were conducted. It was found in later data reduction that the lower sea conditions were representative of high State 3 to low State 4. The higher seas were determined to be equivalent to lower State 5.

Rough water matrix trials formed a major part of the trials completed. A sketch defning the maneuvers used in the RHS 200 matrix trials is given in Figure 41. The tests are intended to provide definition of ship response to head, bow, beam, quartering and following sea encounters. The matrix is based on the assumption that the port and starboard ship responses are equal. The tests were initiated by operating into a head sea for a sufficient period to allow speed to settle out under constant power conditions. The power settings established at that time were maintained throughout the course of the matrix. Each leg of the matrix was continued for a finite period of time or until a minimum of 200 wave encounters had occurred. The time period used in the hullborne tests was 10 minutes. This was reduced to 5 minutes in the foilborne tests. In the interests of conserving test time, the 180 degree turn at the end of test segment 5, test

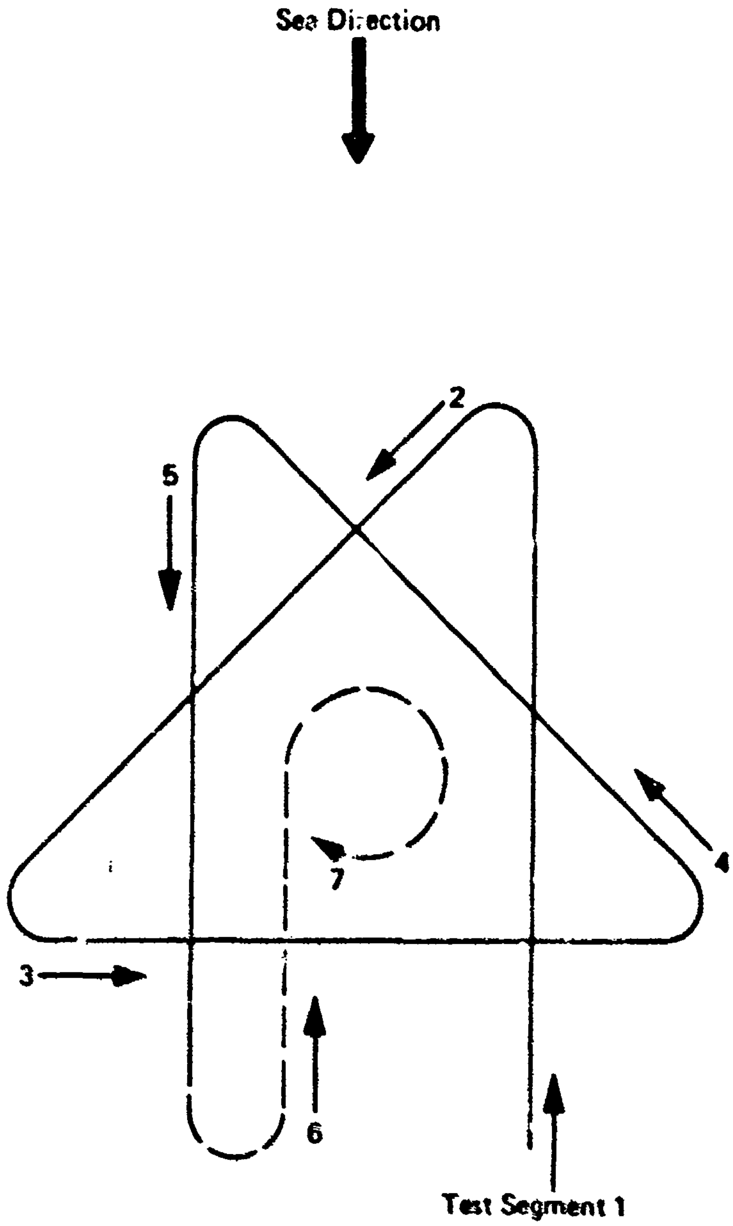


Figure 41 - Rough Water Trials Matrix

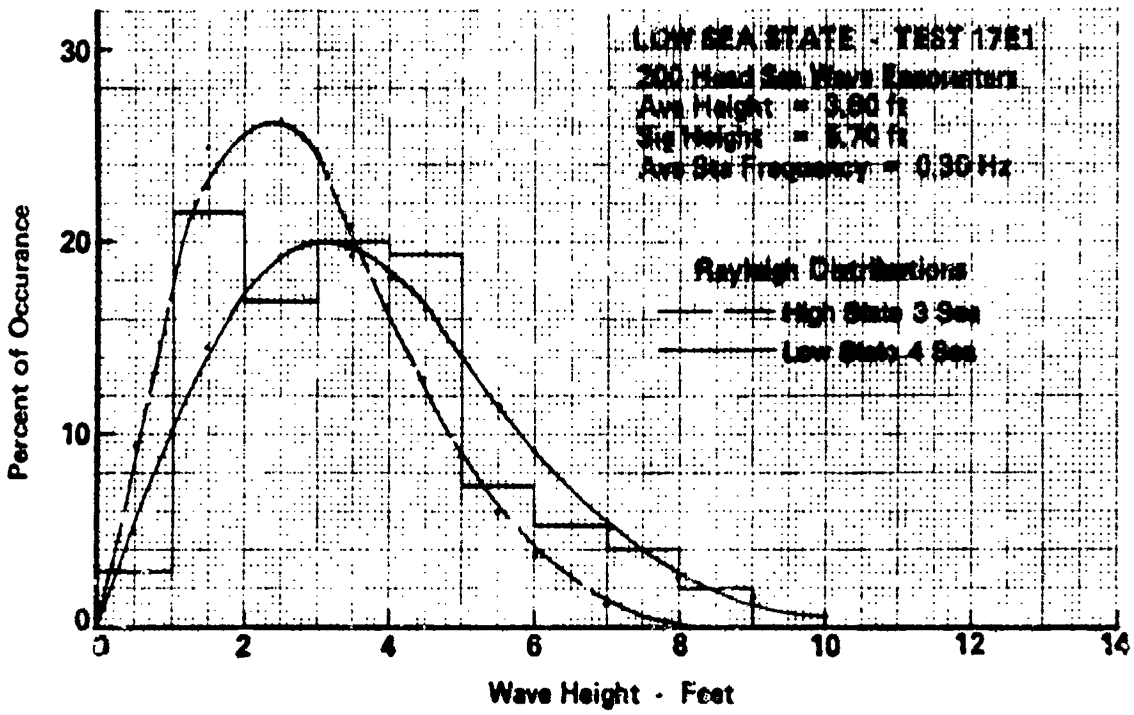
segment 6, and the 360 degree turn of test segment 7 were eliminated from the trials. Matrix segment 6 duplicated segment 1 and it was presumed that the 135 degree turns between the various matrix segments could provide adequate definition of normal rough water turning.

Hullborne and foilborne matrix trials were completed in State 3 seas. Foilborne matrix trials were completed in lower State 5 seas. A test speed of 18 knots was set during the hullborne tests and 28 knots in the foilborne. The hullborne tests were performed with the SAS in the Manual mode. All of the foilborne matrix trials were performed with the SAS aligned to the Automatic mode and were repeated with the SAS in the Manual mode. In the Automatic mode the SAS is fully active in response to the sea. In the Manual mode the SAS is essentially secured except that the Captain can position the flaps to adjust for mean roll, pitch and heave attitudes if desired. The terms "SAS Active" and "SAS Secured" are used to identify the SAS Automatic and Manual modes respectively in the figures included in this report.

Two head sea takeoff tests were completed in State 5 seas during the first day of rough water trials. During the second day of rough water testing head, bow, beam, quartering, and following sea takeoff tests were completed in State 3 seas. Dieudonne spiral turns were attempted in the lower sea condition. These tests were cancelled when it became apparent that they could not be performed with adequate test control. That is, relative heading of the sea could not be maintained through the sequence of differing rudder commands. It was later demonstrated that rudder authority was maintained with 2 degree rudder commands in both head and following State 3 sea conditions.

Sea Conditions

The DTNSRDC-HYSTUDET wave height instrumentation installed on the bow of the ship was used to measure the height of the seas encountered in the rough water trials. The wave height data obtained during the head sea segments of the foilborne matrix trials with the SAS Active were analyzed to determine the sea conditions present. The sea classifications were based solely on height. Manual counts of at least 200 trough-to-peak wave heights were used to construct the height histograms which are given in Figure 42. The histograms are shown in



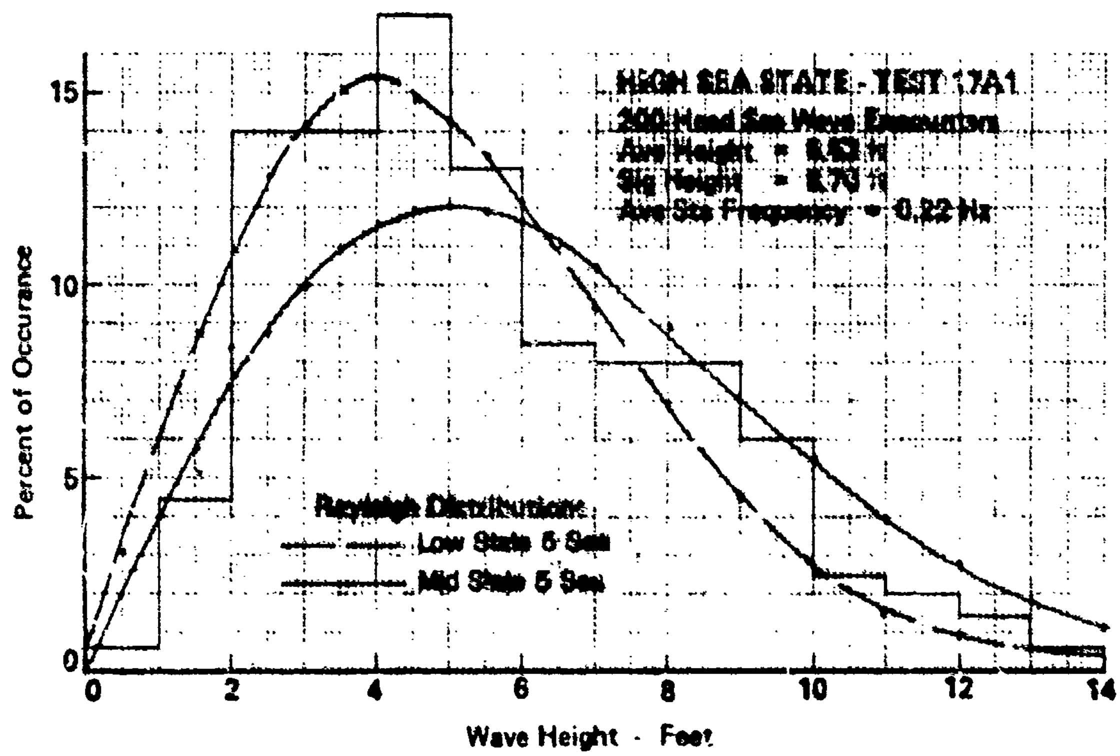


Figure 42 - Wave Height Histograms

comparison with theoretical Raleigh distribution curves for some closely comparable sea conditions. The Raleigh distributions were computed based on significant wave heights as compiled by Wilbur Marks of the then designated David Taylor Model Basin. The lower sea condition histogram contains too large a percentage of waves over 6 feet in height to be classed solely as high State 3 sea. Conversely, the percentage content of waves up to 5 feet in height is too high to permit a lower State 4 sea classification. A combined description of high State 3 to lower State 4 is appropriate. The wave height histogram for the high sea condition tests shown in Figure 42 displays a distribution which closely approximates the theoretical distribution for a lower State 5 sea. The distribution contains far too high a percentage of waves in the 2 to 6 foot height range to be considered as a higher sea condition. The average stationary frequency of the head sea wave encounters which are included in Figure 42 were developed from Bretschneider spectrum analysis transforms which is presented in Reference (10).

The average and significant wave heights for the histograms of Figure 42 are compared with similar data obtained during the remainder of the foilborne matrix trials in Figure 43. This latter data was also developed from manual counts of wave height. They were prepared to establish that the same sea conditions were present throughout each matrix. The range of average and significant wave heights which are used to identify State 3, 4, and 5 seas in the Marks compilation are included as right-hand ordinates in the figure. The test designations given in the figure are used here, and throughout the remainder of the rough water discussions, to identify particular test series. They are defined as follows:

Test	Sea Condition	SAS Alignment
17A	Low 5	Automatic (Active)
17B	Low 5	Manual (Secured)
17E	High 3	Automatic (Active)
17F	High 3	Manual (Secured)

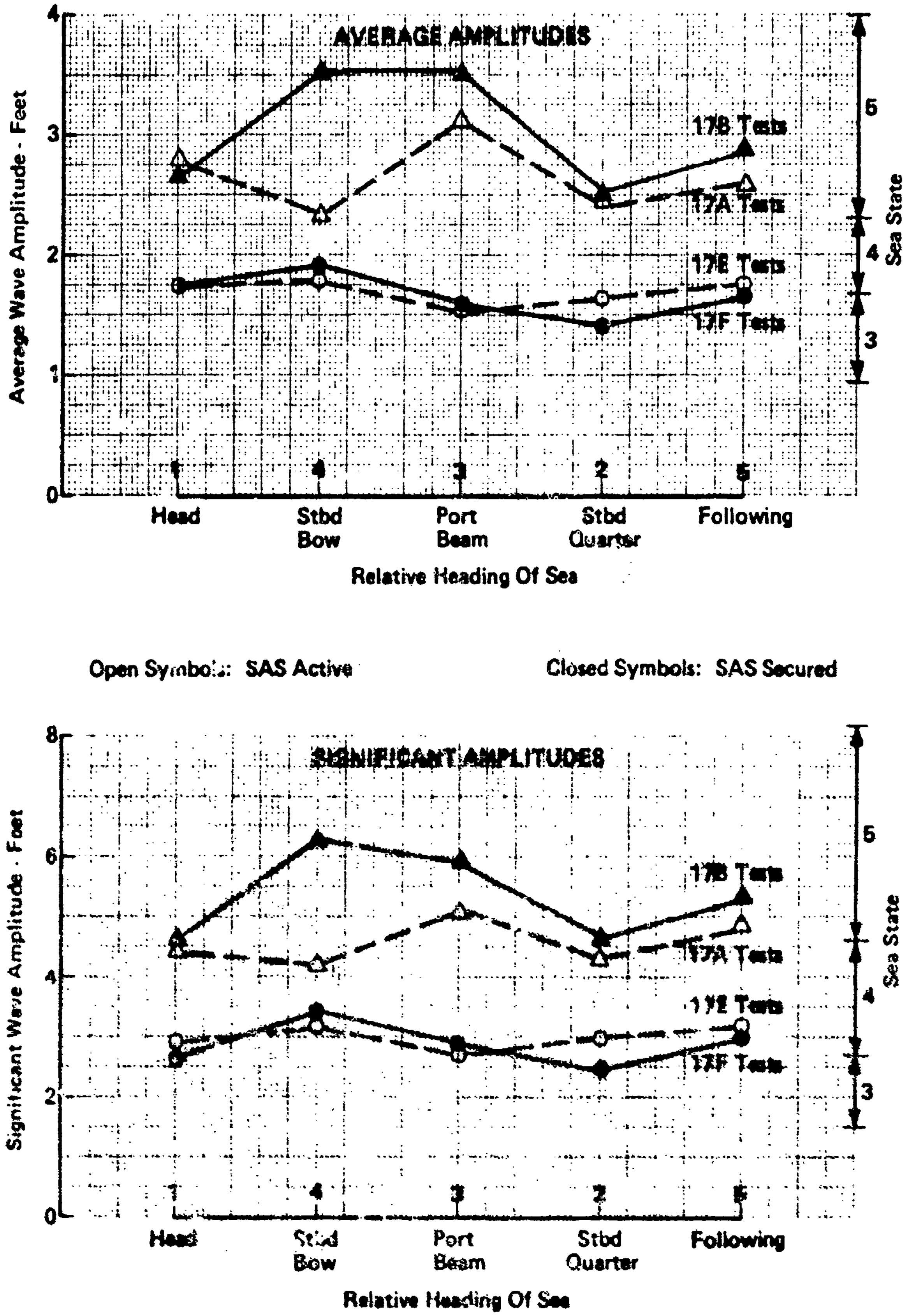


Figure 43 - Test Sea Conditions

All of the 17A and 17B tests were conducted in low State 5 seas. There is indication that the seas were slightly higher during the conduct of the 17B tests with the SAS secured. This is possible since the seas were building throughout the day and the 17B tests were the last conducted. The large difference between the wave heights registered during the starboard bow segments of tests 17A and 17B were confirmed by review of both sets of data. Upper State 3 to lower State 4 conditions were present throughout the 17E and 17F tests. The numerals included along the abscissas of Figure 43 identify the test matrix segment and the order of test.

The classification of sea conditions presented in Figures 42 and 43 is believed to be conservative. As noted, wave height was measured using the installed wave height instrumentation system. In this equipment the output of a vertical accelerometer, which is gyro stabilized in pitch and roll, is double integrated to define vertical displacement of the ship above a still water level reference plane. The accelerometer originally installed and calibrated in the system was found to be inoperative after shipment to Messina. A second unit was located and forwarded to the on-site trials team. This unit was installed into the wave height system and was used for the conduct of all rough water trials. The outputs of the two accelerometers were expected to be closely comparable and post-trial calibration tests were planned to provide minor redefinition of the original calibration data. The post-trial calibration tests yielded significantly different results. The initial wave height calibration factor was 4.35 feet per volt. The post-trial calibration factor was 5.65 feet per volt. The original accelerometer was totally inoperative and the instrumentation section of the wave height equipment had been throughly doused with sea water during the trials. There were no means available to reconcile these differences. In the opinion of the DTNSRDC-HYSTUDET Trials Director the use of the higher calibration factor would identify sea conditions which were higher than those believed to be present during the trials. For example, if the higher factors were used the lower seas encountered in the tests would be classed as high 4 to low State 5 and the higher seas encountered classed as middle to high State 5. The conservative approach was selected and the lower calibration factor was used in the reduction of the wave height data.

Data Analysis Notes

Several approaches were used in the reduction of the rough water test data. The analysis procedures used were somewhat dependent on the nature of the data. Rough water speed and powering data obtained during the trials were reduced using procedures which closely paralleled those of the calm water tests. A number of 20 to 30 second TDAS data intervals were taken along each segment of each test matrix. The data of these intervals were processed exactly as the calm water data. A final average was taken and used to represent the speed-power conditions for a particular segment of a particular matrix trial. The rough water takeoff trials data were also reduced in the same manner as the calm water trials. That is, the speed and power, time, and distance calculations were all based on one second TDAS data intervals.

The reduction of the ship rough water motion and acceleration data was approached on various frequency analysis bases. Eventually, all of the following forms of analysis were used or were attempted.

a. Computer derived Power Spectural Density (PSD) plots were generated for all of the rough water data except the speed and power parameters.

b. Manually derived histograms were prepared for all of the wave height and most of the pitch and roll angle data.

c. A Fast Fourier Transform (FFT) digital Real Time Analyzer (RTA) was used to provide normal, non-PSD, spectral analysis of some of the pitch and roll data and most of the accelerometer data.

Initially, all of the wave height, pitch and roll angle, yaw rate, flap angle and accelerometer data obtained during the rough water trials were input to a contractor computer facility for PSD analysis. PSD plots were generated for each of these parameters, and mean values were also generated for each of the

above parameters during each leg of each matrix. Root Mean Square (RMS), standard deviation, and mean values were also generated for each of the above parameters at each test condition as a part of the PSD analysis. At this stage of the analysis it was planned to use the PSD derived RMS values and the factors given in Table 5.7 of Reference (9) to estimate the average one-third, or significant, and one-tenth highest values of the various rough water parameters.

Satisfactory use of the RMS based estimates requires that the data approximate Rayleigh statistical distribution. Strip charts were used to manually define histograms of some of the wave height and pitch and roll angle data. RMS, standard deviation, and mean values were also derived from the histogram data. The wave height data did not. In addition, little agreement was found between PSD and manually derived RMS values for either the wave height or the pitch and roll angle data. Investigation into the source of the lack of numerical agreement disclosed that the PSD plots were based on single spectra which typically represented only 18 to 20 seconds of data. Wave encounter and ship roll and pitch response frequencies were too low to be adequately defined by such brief bursts of data. The computer used in the PSD analysis was not programmed to process and average consecutive spectra from a long term data stream. Reprogramming could not be accomplished within existing time and budget constraints. The PSD plots and accompanying data could not be used with confidence.

At this point, a decision was made to use manual procedures to define the statistical characteristics of all of the wave height, pitch angle and roll angle rough water data. The frequency of the sea and the response of the RHS 200 in pitch and roll was sufficiently low to permit accurate, albeit, tedious, manual statistical counts of maximum and minimum values to be made.

A review of strip chart data traces for the seven accelerometers installed throughout the ship indicated that relatively high frequency responses were being carried on top of the low frequency, direct sea response. Since the high frequency data could not be processed manually, a Nicolet, Model 444b, digital RTA was used in the analysis of the state 5 sea accelerometer data. It was decided to use an upper frequency limit of 10 Hz in the analysis of this data. This limit was judged high enough to capture the higher frequency response data and low enough to avoid inclusion of acceleration components which might result from

the propulsion systems. The RTA analysis is based on 400 line elements. The frequency selection provided an equivalent 0.4 Hz filter bandwidth. The selection of a 10 Hz frequency limit also establishes a relatively slow RTA sampling rate. On the average, 8 consecutive spectra were obtained and averaged from the data recorded during any leg of the matrix trials. Data playback errors, which increased with repeated playbacks, prevented continuous analysis in many cases and negatively influenced the number of spectra which could be taken. It was determined during the analysis that RTA defined standard deviation values could be repeated within 90 percent or better if more than 5 to 6 spectra were averaged. The level of repeatability would have been improved if data intervals, longer than the 5 minutes used in the trials, would have been available.

Numerous playback errors occurred in most of the accelerometer data recorded during the state 3 sea trials. The discrepancies were sufficient to prevent input of this data to the RTA. The limited value, PSD study results were used in its presentation within this report.

The RTA was not used in the analysis of the wave height, pitch and roll angle data. The Model 444b RTA was designed for primary use in the analysis of acoustic and vibration signatures and determines data standard deviations taken about a mean value. The mean value is typically zero in acoustic and vibration applications and it is not processed by the RTA. Non-zero mean values can be expected in the case of ship motions while operating in a seaway.

A casual approach to the use of the term "RMS Value" was noted during the development of the PSD data and the RTA analysis results. A lack of specific definition can lead to misinterpretation of the data when non-zero mean values exist. For reference purposes it is noted that all of the rough water data in this report has been developed and is presented in accordance with the standard statistical expression:

$$(\text{RMS})^2 = (\text{Standard Deviation})^2 + (\text{Mean Value})^2$$

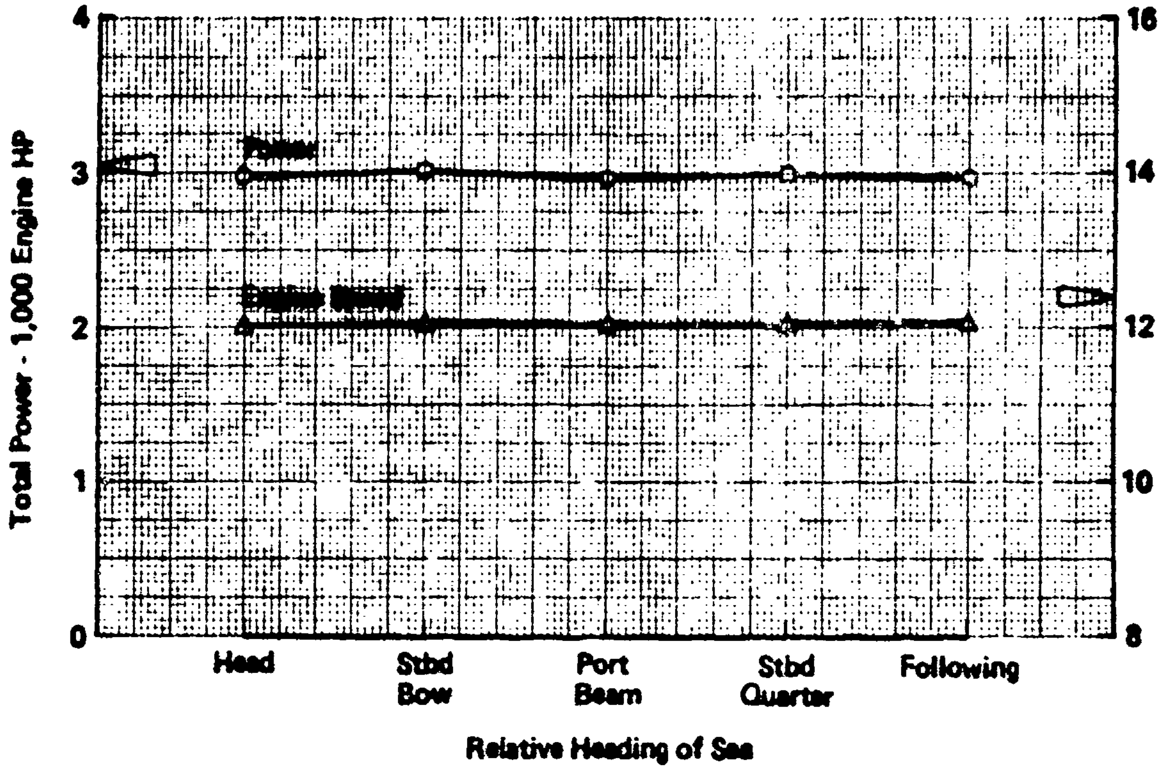
ROUGH WATER SHIP PERFORMANCE

Hullborne Speed and Power

Hullborne speed and powering data for the RHS 200 in State 3 seas is given in Figure 44. The mean speed of the tests was slightly below 19 knots. Corresponding calm water powering data are identified by the indicators positioned along the ordinates within the figure. These calm water data have been defined through extrapolation of the faired data curves of Figure 7. There is essentially no difference between the calm water and the State 3 hullborne speed and power requirements. The relatively minor effects which result from changes in relative heading of the sea are as should be expected. Engine speed and power levels were maintained constant as required throughout the test matrix. The increased drag associated with a head sea operation resulted in a loss in ship speed. Speed apparently was gained with a following State 3 sea. The similar slope present in the range data is largely due to the change in speed. At reduced speed of advance and constant engine speed some increase in propeller thrust should theoretically occur. It should also be accompanied by an increase in power when rpm is constant.

Rough Water Takeoffs

Power, time and distance data for the rough water takeoff trials performed in State 3 seas are given in Figure 45. Two separate takeoffs were performed at each relative sea heading during the tests. There were no significant differences between the various pairs of data. The application of power did not differ to a noticeable degree between any of the five takeoffs included in the figure. In terms of time required to takeoff there are no appreciable differences within the data. The two separate curves included in the lower section of Figure 45 encompass the time related results of all the tests. The lower curve which conforms to the quartering sea takeoff, defines a 10 to 20 knot time interval which a 1 second less, 8 seconds as opposed to 9, than that denoted by the curve for the head sea data. Ship acceleration immediately above 29 knots is the same for all headings. The distance indicators included in the figure relate to the head



◁ Extrapolated Corresponding Calm Water Values At 18.7 Knots

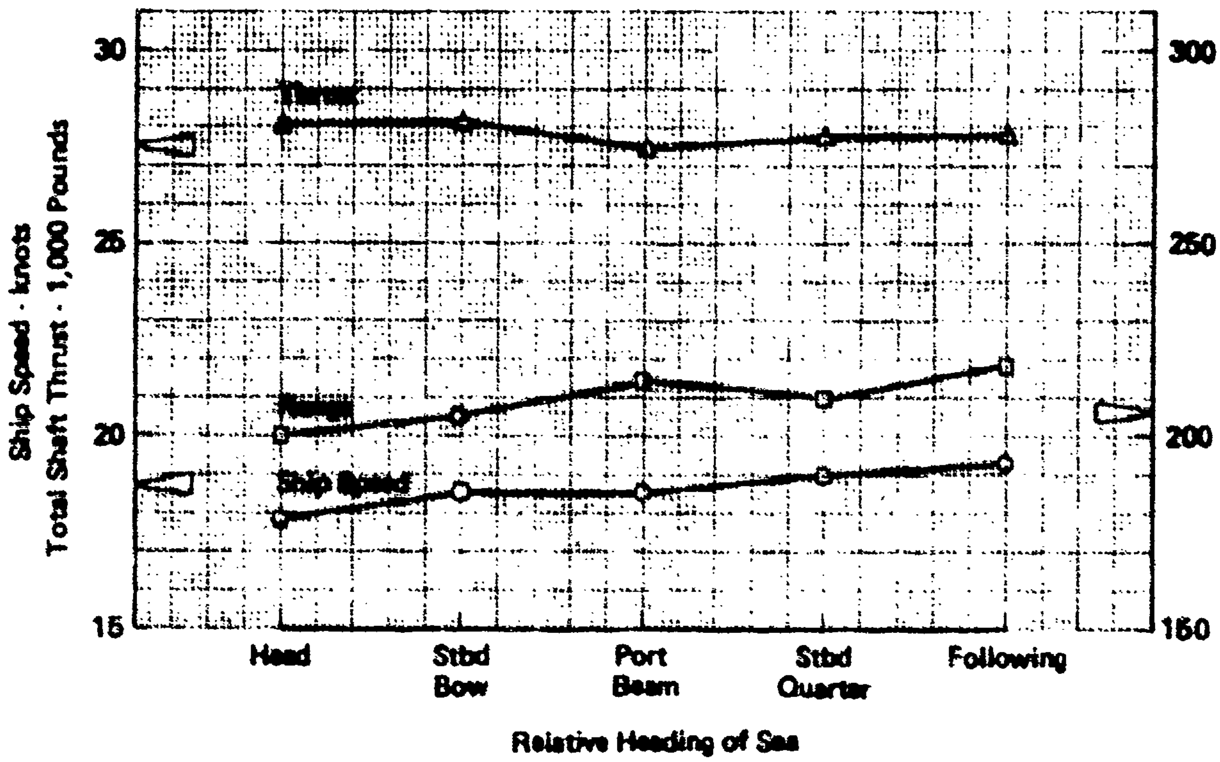


Figure 44 - Hullborne Speed and Power in State 3 Seas

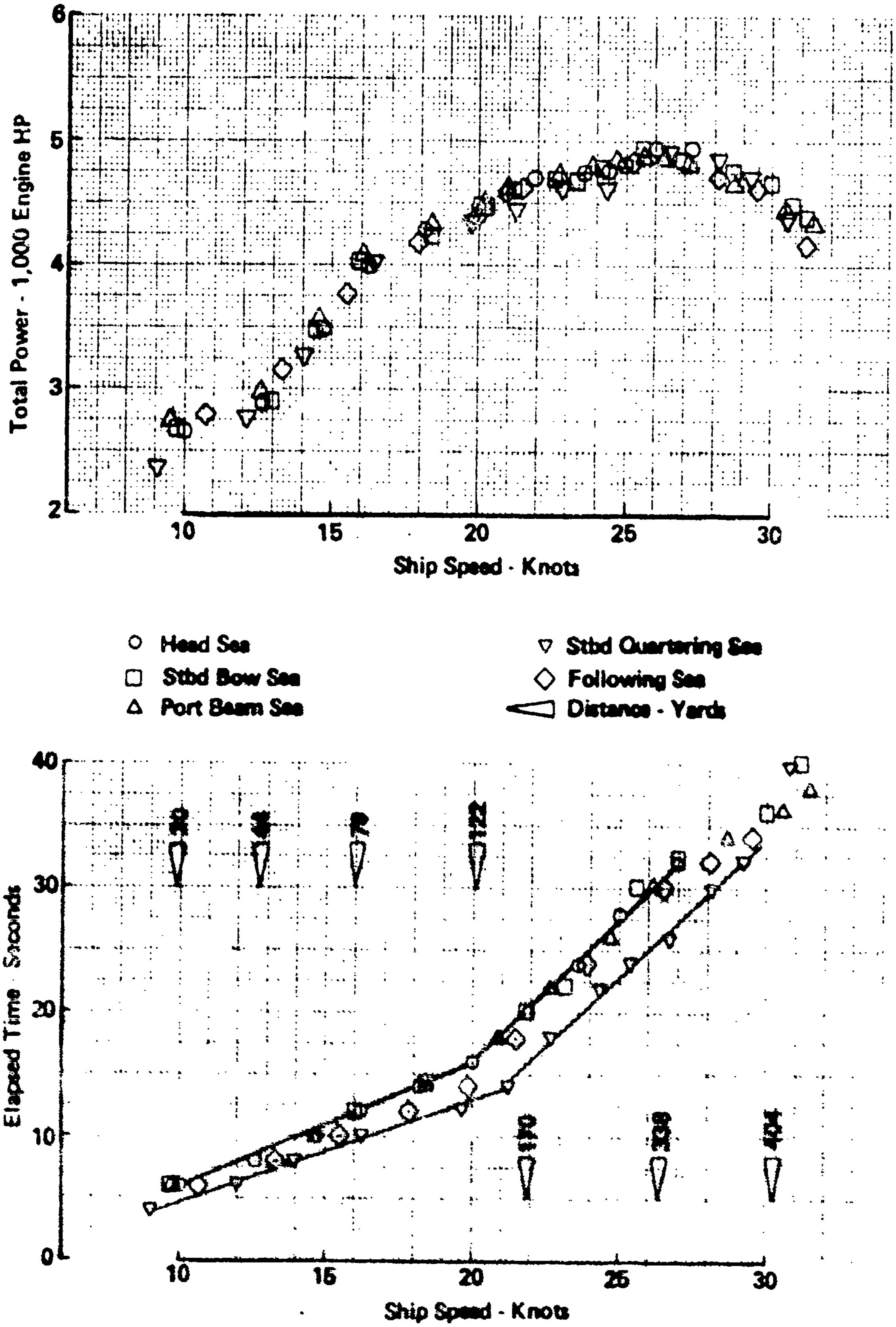


Figure 45 - Takeoff Performance in State 3 Seas

sea takeoff data. These results are compared with calm water takeoff characteristics in later discussion.

Test data for one of the two head sea takeoffs which were performed in State 5 seas are given in Figure 46. At first inspection the data appear to be very similar to that presented for other takeoff tests. The comparison of calm and rough water takeoff performances given in Figure 47 indicates that during the State 5 takeoff higher power levels were maintained while in the 10 to 17 knot speed range and that lower maximum power setting was used. The impact, if any, which these differences may have had on takeoft performance can be interpreted from the time versus speed curves in the lower section of Figure 47. The curves have all been vertically adjusted to a common 5 second time point at 10 knots. As should be expected, the calm water takeoffs require less time but, the time required to complete the rough water takeoffs is not appreciably greater. No difference could be found between the State 3 and 5 takeoffs in the 10 to 20 knot speed regime. It is possible that the increased power levels which were applied at lower speed may be obscuring differences due to sea. In the higher speed region there is no difference between the State 3 and 5 takeoff times regardless of the fact that less power was applied in the higher sea test. The data presented show that the sea conditions encountered during these tests did not adversely effect RHS 200 takeoff performance to a significant degree.

Foilborne Speed and Power

Foilborne speed and powering characteristics for the RHS 200 in State 3 seas are given in Figure 48. The data were obtained during the matrix trials conducted with the SAS aligned to the Automatic mode. The data obtained during the same tests with the SAS in the Manual mode were reduced but have not been presented because they did not differ from the given data. The foilborne State 3 tests were performed at an average ship speed of approximately 33 knots. The data are compared with heavy ship calm water test data at the same speed taken from Figure 7. There is no appreciable difference between foilborne operation in calm water and in State 3 seas.

The speed and powering characteristics of the ship in State 5 seas are given in Figure 49. The tests with the SAS active were performed at an average

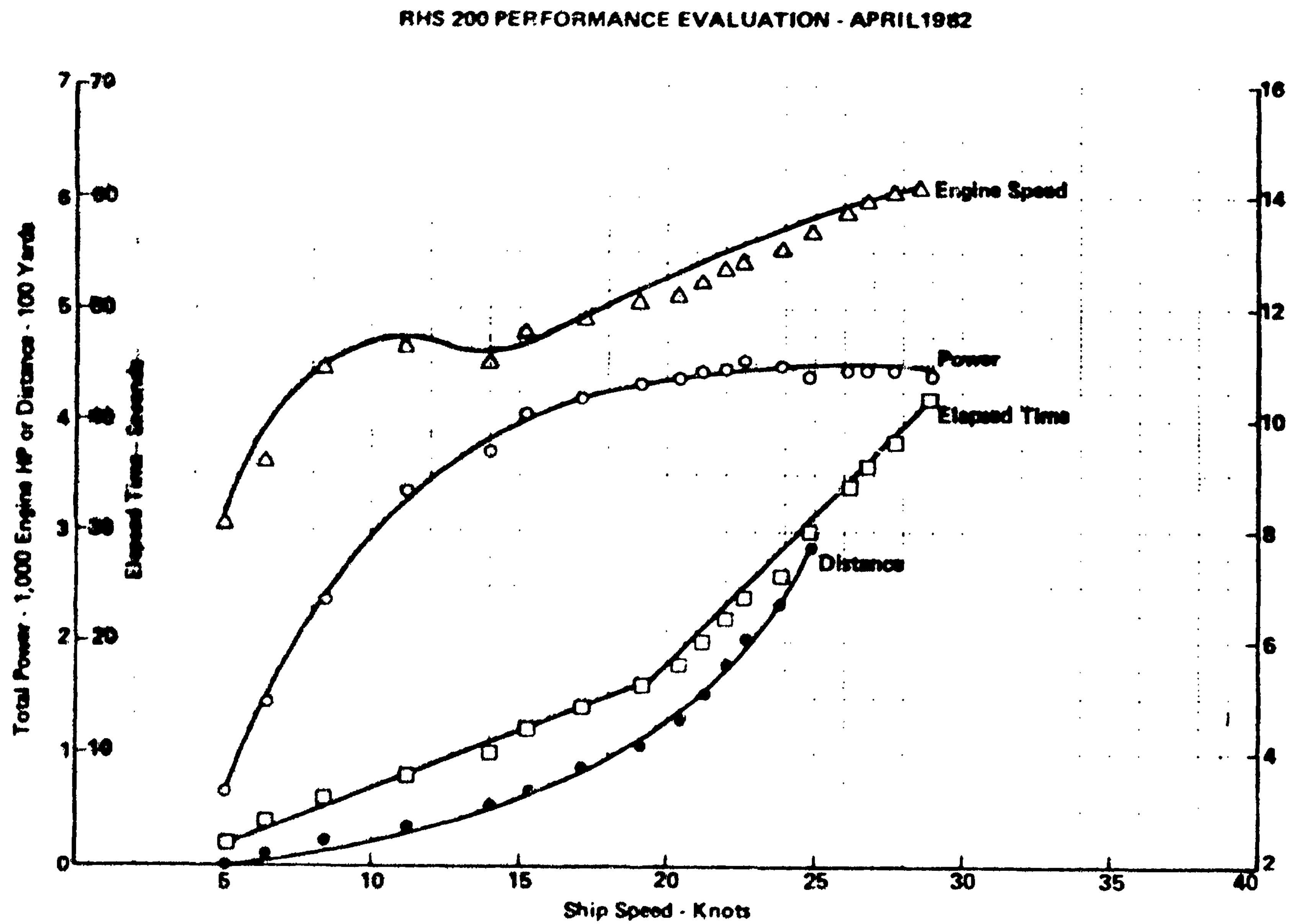


Figure 46 - Takeoff Performance in State 5 Seas

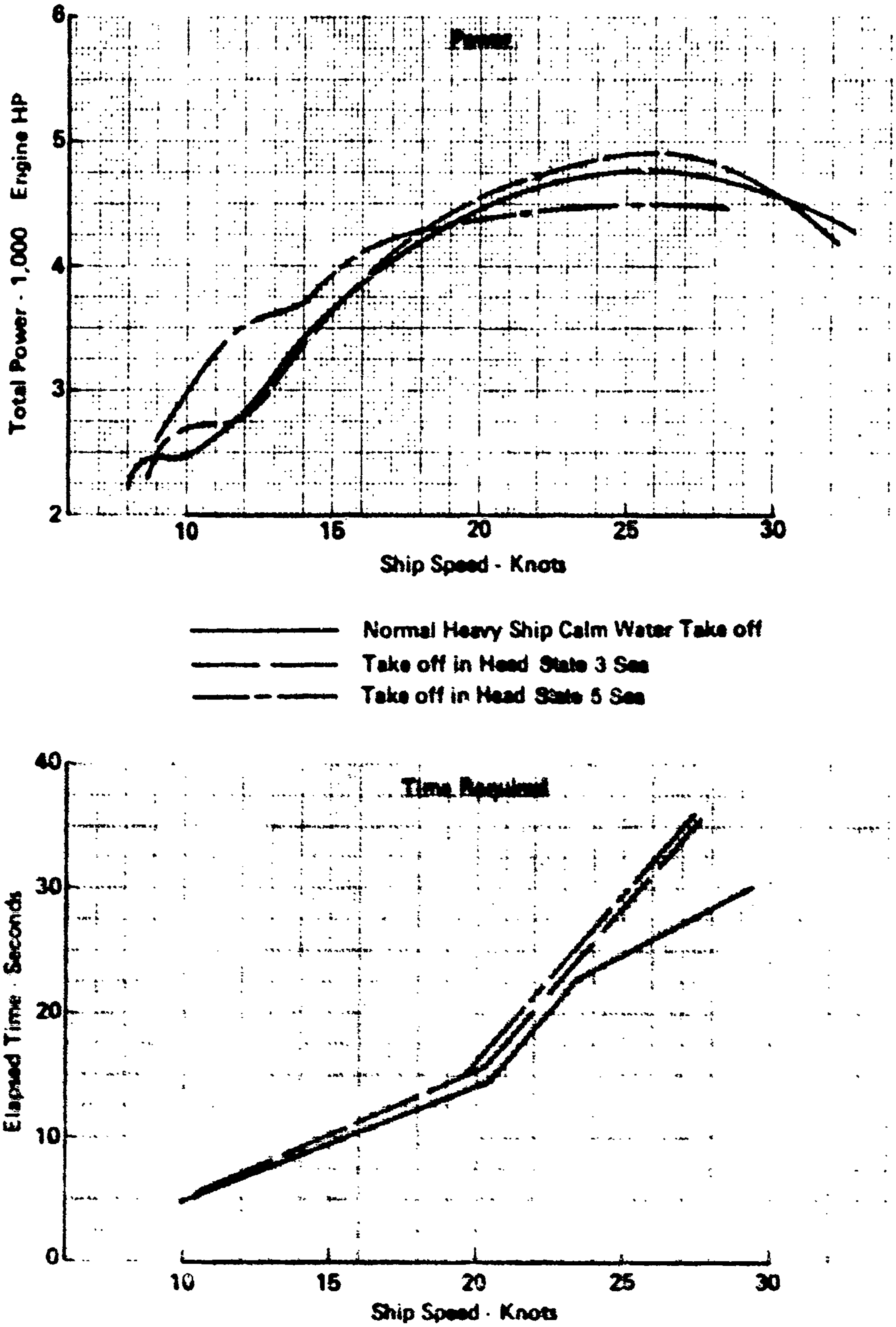
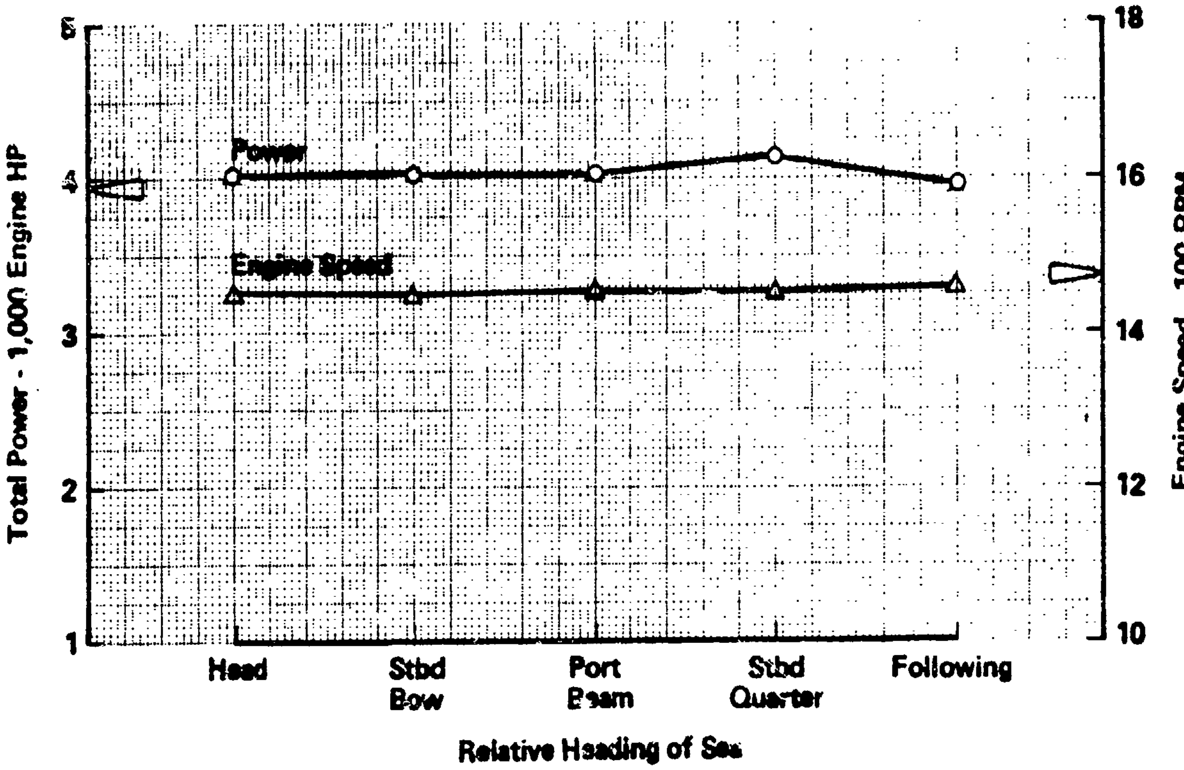


Figure 47 - Calm and Rough Water Takeoff Comparisons



Corresponding Calm Water Values At 32.9 Knots

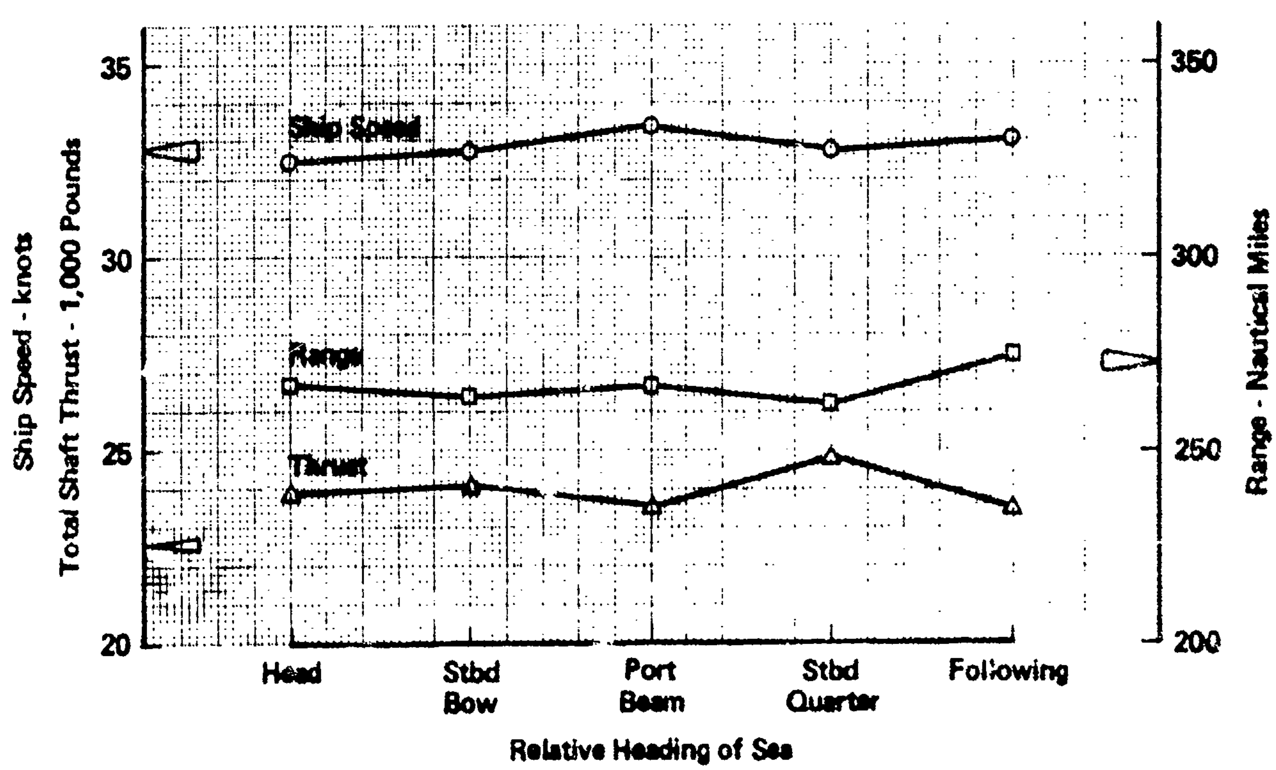
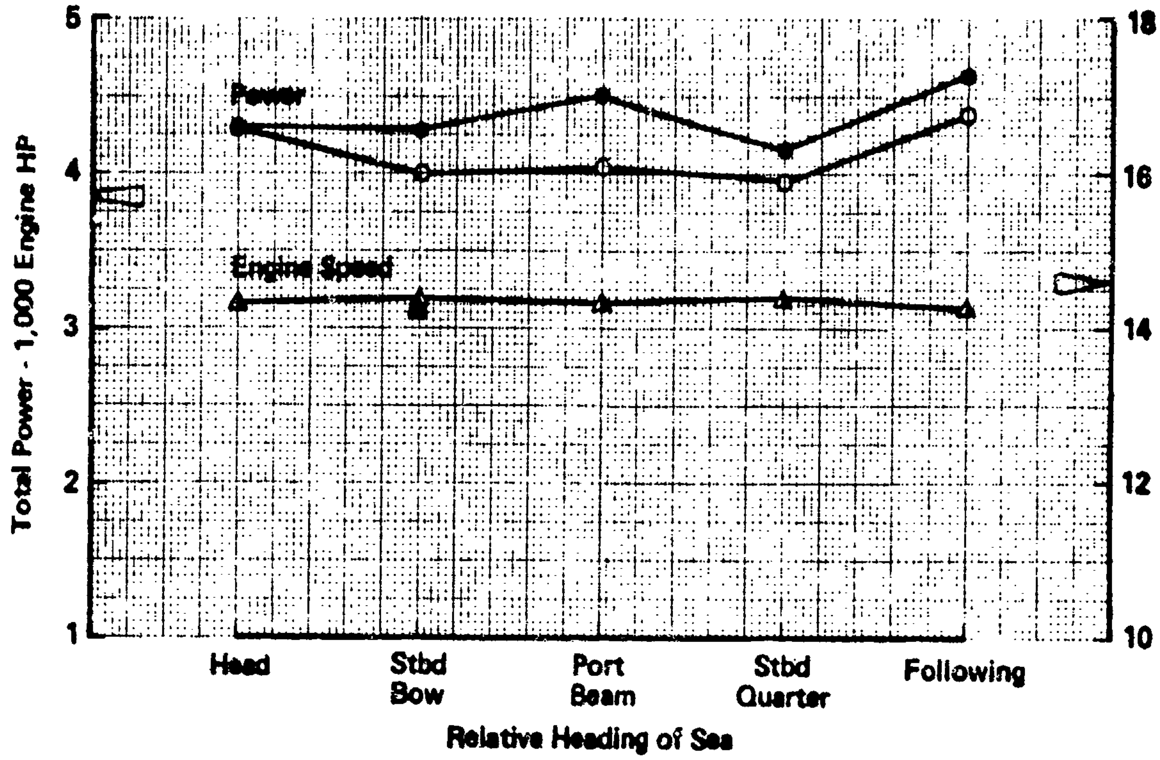


Figure 48 - Foilborne Speed and Power in State 3 Seas - SAS Active



Corresponding Calm Water Values At 30.9 Knots

Open Symbols: SAS Active Closed Symbols: SAS Secured

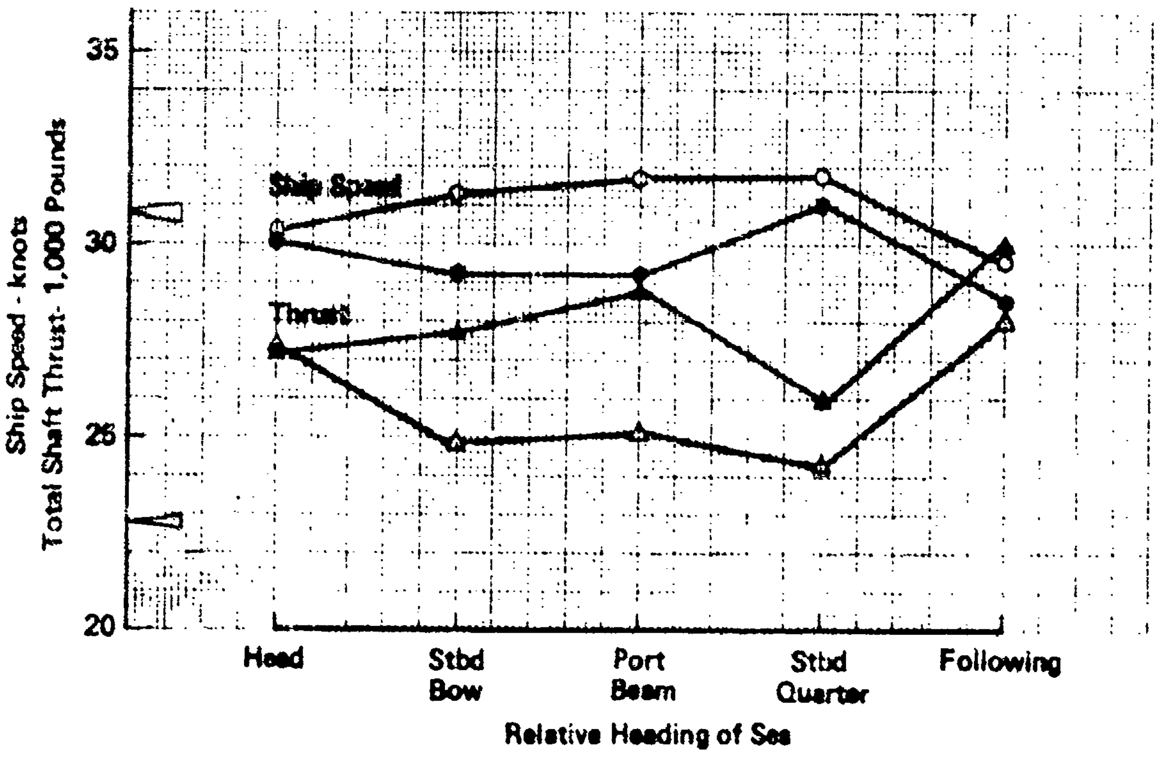


Figure 49 - Foilborne Speed and Power in State 5 Seas

speed of 31 knots. The power requirement in these tests were between 8 and 18 percent higher than calm water levels. Higher power levels were required in the tests with the SAS secured. These tests were at an average speed of 29.6 knots and, according to Figure 43, were performed under higher sea conditions. The combination of these factors resulted in power increased of 17 to 31 percent in comparison to the 29.6 knot calm water requirement. The thrust data trends of Figure 49 are consistent with the power data.

The effect of State 5 sea operation on foilborne range are given in Figure 50. Ship range capability is adversely effected by decreases in speed and increases in power. Consequently, the differences due to sea are more pronounced when ship range is considered. The average range reduction is 17 percent for operation with the SAS active and is at 28 percent with the SAS secured.

The limits of RHS 200 foilborne operational capability in a following sea were reached during the State 5 seas matrix trials which were performed with the SAS in the Manual mode. During the latter stages of this trial segment the ship was no longer foilborne and the engines were operating at overload conditions as indicated by alarms at the Engineer's station. The matrix trials were terminated at this time. The high power levels recorded during the beam sea operation without the SAS and during the following sea test with the SAS indicate that the ship was, at these times, nearer to an operational limit than was realized at the time of the trials.

Rough Water Turning

During the rough water trials the turns required between the successive matrix segments were executed at the discretion of the Captain of the ship. The data acquisition system was on-line during these maneuvers and the data recorded has been reduced for use in the absence of other information. The results are summarized in Table 15. During the State 5 trials port rudder commands averaging over 16 degrees were typically used. The resulting turn rates were generally slightly less than 2 degrees per second to the port. These rates, at these commands are in close agreement with port turning characteristics defined in the spiral turns of Figure 22. The SAS is not used to control ship turning therefore the fact that there is no difference between the State 3 turns with and without the SAS should be expected.

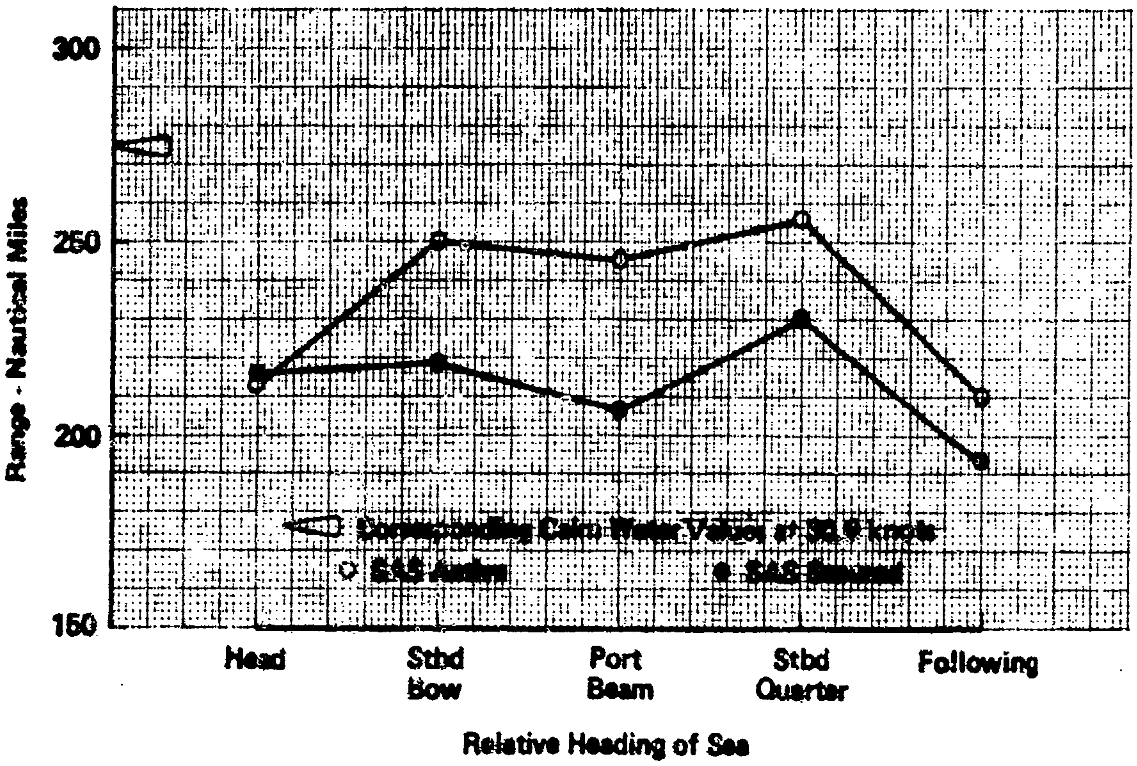


Figure 50 - Foilborne Range in State 5 Seas

TABLE 15 - FOILBORNE ROUGH WATER TURNING

CHANGE IN RELATIVE SEA HEADING	SAS ACTIVE		SAS SECURED	
	RUDDER POSITION DEGREES	TURN RATE DEG/SEC	RUDDER POSITION DEGREES	TURN RATE DEG/SEC
State 3 Sea Tests:				
From Head to Stbd Quarter	-16.8	-1.85	-16.2	-1.88
From Stbd Quarter to Port Beam	-16.5	-1.45	-14.5	-1.35
From Port Beam to Stbd Bow	-17.0	-1.93	-15.0	-1.93[2]
From Stbd Bow to Following	-17.8	-1.75	-18.4	-2.08
State 5 Sea Tests:				
From Head to Stbd Quarter	-14.3	-1.77	-10.0	-1.26
From Stbd Quarter to Port Beam	-11.4	-1.39	- 8.0[3]	-0.73
From Port Beam to Stbd Bow	-11.4	-1.53	-11.7[4]	-1.17
From Stbd Bow to Following	-11.0	-1.35	-11.1[4]	-1.29

Notes:

1. The test matrix used in the trials only included turns to port.

2. The helm was advanced relatively slowly over 13 to 15 seconds instead of normal advancement in 3 to 5 seconds.

3. The rudder position was frequently adjusted between 2 to 11 degrees left during the turn. The value given is a time weighted average.

4. The SAS was active during these turns.

In the initial State 5 tests with the SAS active a rudder command of approximately 15 degrees was used to turn from the head sea to the starboard quartering sea conditions. The turn rate achieved was comparable with calm water turning capability. In all subsequent turns within this matrix the Captain elected to use a nominal 10 degree port rudder command. The turn rates which resulted are also compatible with calm water turning capability. During the tests with the SAS in the Manual mode, the first turn, from a head to starboard quartering sea, was made without difficulty with 10 degrees of rudder. Increased difficulty was encountered in the next turn when moving to the port beam sea condition. During this turn it was necessary to frequently ease the helm as the ship was brought around to the beam sea. In performing both of the remaining turns in this trials matrix the Captain of the RHS 200 elected to use the SAS Automatic mode. With the SAS active it was possible to hold rudder positions which were nominally 10 degrees port. The turn rates which resulted were lower than previous. It has been noted that the seas were building as the day progressed. The increase in sea could be reflected in the reduced turn rates.

ROUGH WATER RESPONSE CHARACTERISTICS

Relatively large quantities of information were generated in the analysis of the RHS 200 rough water motions and accelerations. Since much of the information supports, but does not bear directly on the presentation of the main results, its immediate inclusion has been postponed. The principal results of the rough water motion and acceleration data are discussed in the following sections. The bulk of the supportive information is included under the third following section without substantial discussion.

Pitch and Roll Motions

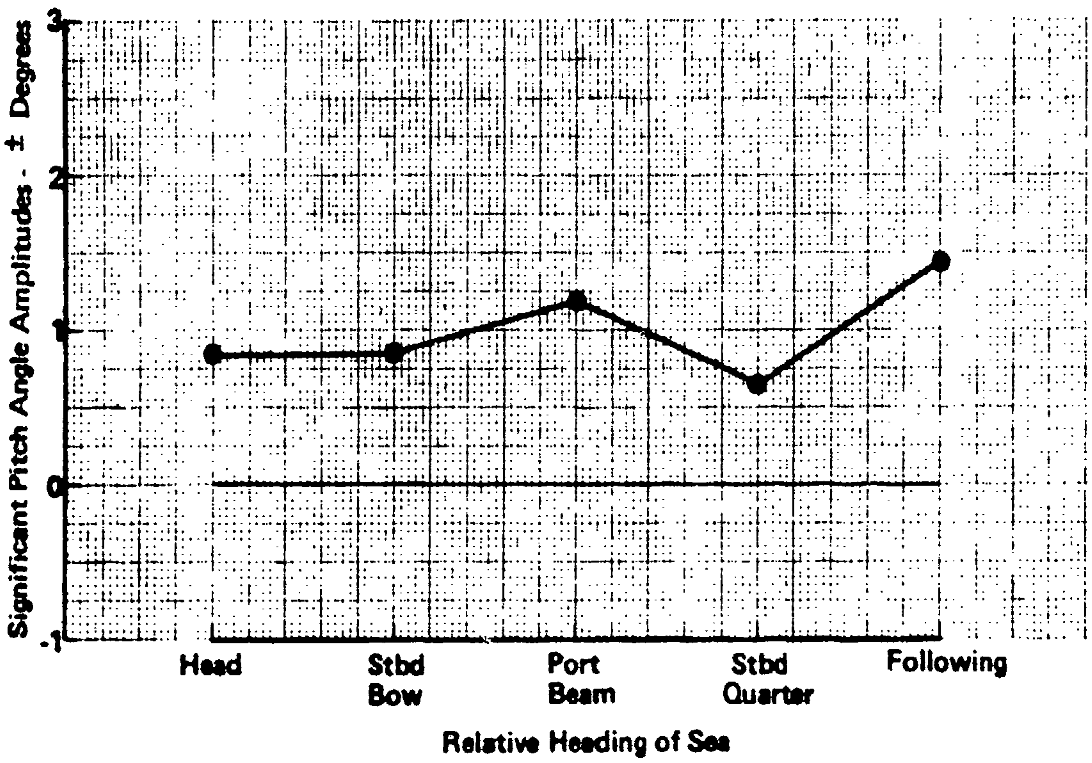
The RHS 200 rough water pitch and roll motions are presented on the basis of significant excursions from mean values. They were derived by first developing a histogram containing at least 400 peak value excursions. Mean, standard deviation, and RMS values were computed from the data and the significant, i.e., average of the one-third highest, and the average one-tenth highest values about

the mean were also determined. The significant values are used in these discussions as representative of the ship motions. The modifier "significant" is to be implied in the use of the terms "pitch" and "roll" in the following discussions. Tables 16 through 19, in the Supportive Information Section, contain listings of the numerical data derived from the histograms.

The pitch and roll angle experienced by the RHS 200 during the State 3 hullborne matrix trials are given in Figure 51. The SAS was in the Manual mode during these tests and they were not repeated with the SAS in the Automatic mode. It was expected that the flaps would not exert sufficient authority at low speed to influence the ride quality of the ship. During these tests the mean value of ship pitch angle was approximately 1.0 degrees. The response of the ship in pitch was reasonably well damped, the significant pitch angle excursions were typically 1.0 degrees about the mean. The mean values of roll angle were on the order of 0.2 degrees. Roll was very well damped in the head and the starboard bow seas. The relatively large increase in roll angles in the beam, quartering and following sea cases results from a low frequency swell which was encountered in the tests. The swell was not noticed at that time but was clearly evident in data playback. Despite this condition none of the angles in Figure 51 represent severe conditions. The foil systems are providing high degrees of dampening.

The pitch motions which resulted with foilborne operation in the State 3 and 5 matrix tests are given in Figure 52. These tests were conducted with the SAS active and secured. In the State 3 sea pitch angle varied between 0.5 to 1.0 degrees, the SAS had little effect on the excursions. In State 5 sea operation the SAS provided a nominal 60 percent reduction in the significant values of pitch angle. Further numerical data relative to these plots is also given in Tables 16 through 19. Data traces of wave height and pitch angle versus time for the head and following sea tests are given in Figures 58 through 61 in the Supportive Information Section. Samples of the flap deflections which were utilized in the State 3 and 5 head and following seas are given in Figures 62 and 63 of that section.

The roll motions encountered during the foilborne State 3 and 5 matrix trials are summarized in Figure 53. The surface-piercing foil systems of the RHS 200 offer a very high degree of stabilization. The significant values of roll



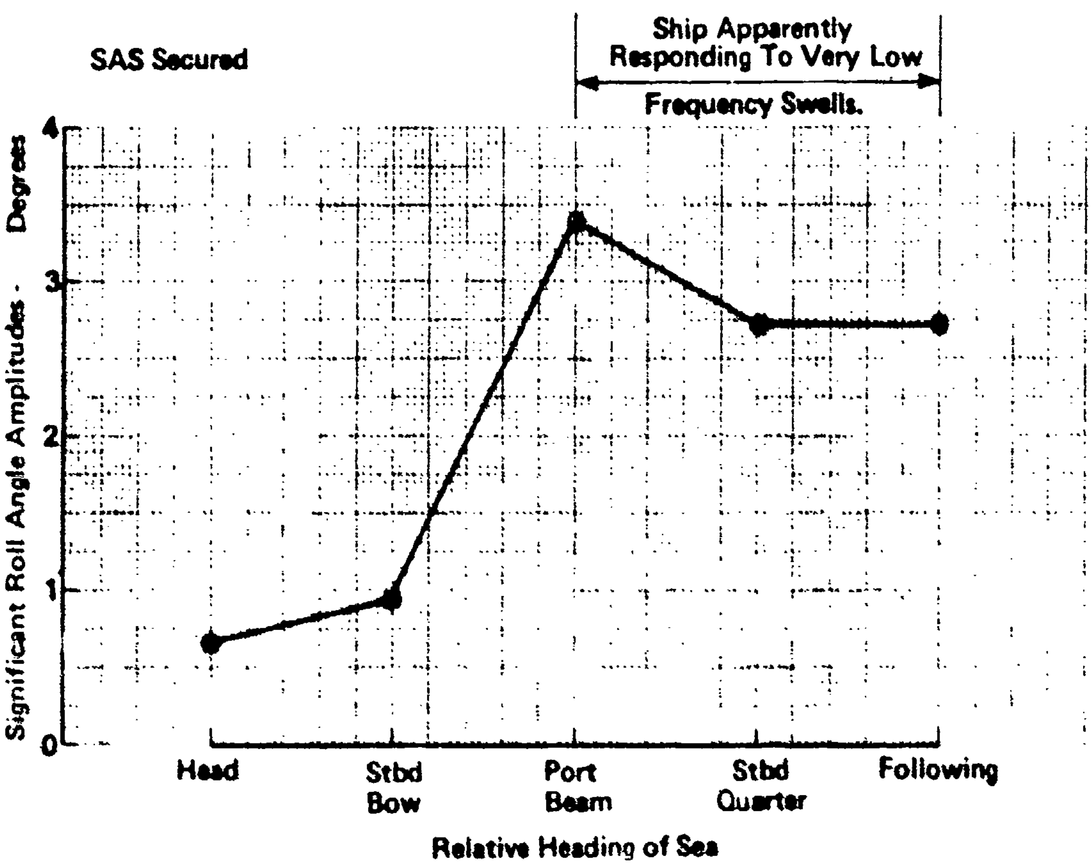
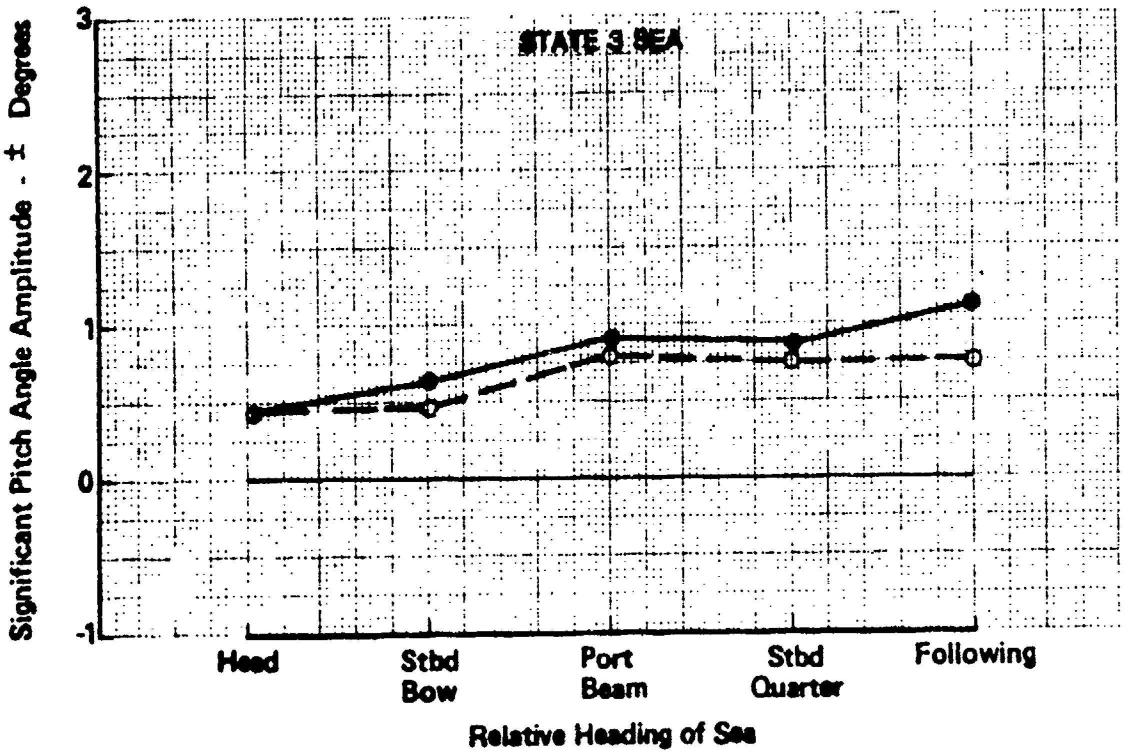


Figure 51 - Hullborne Pitch and Roll Motions in State 3 Seas



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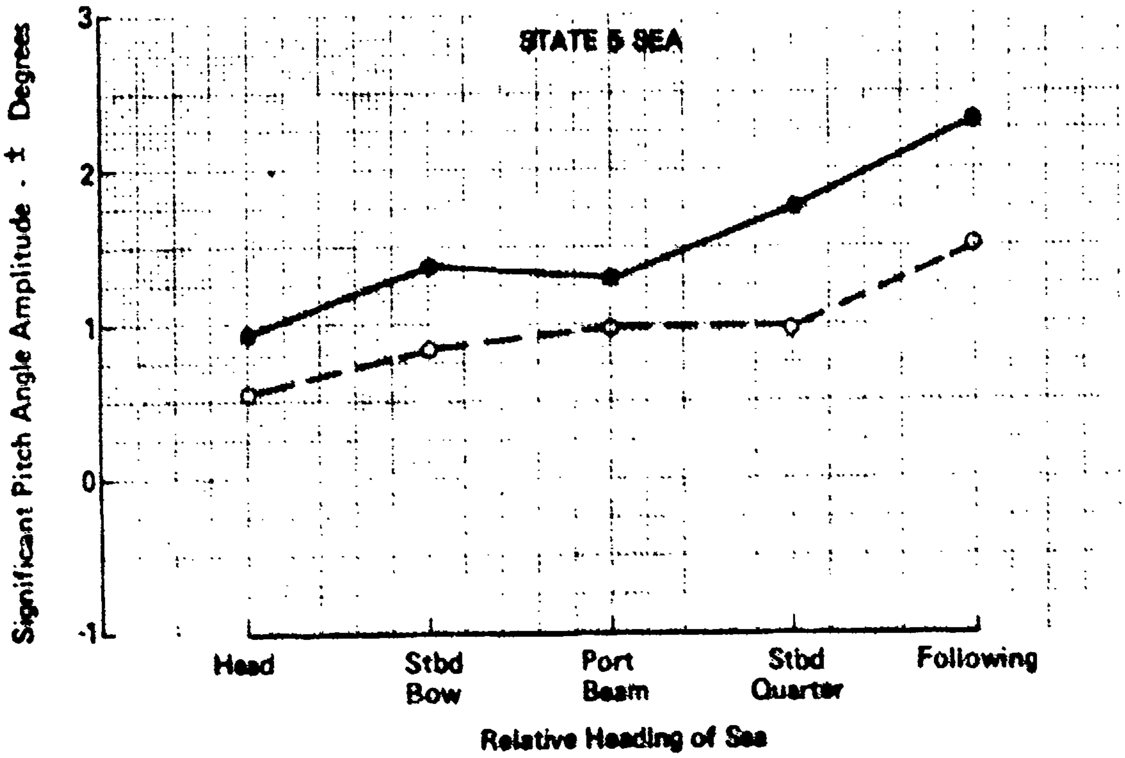
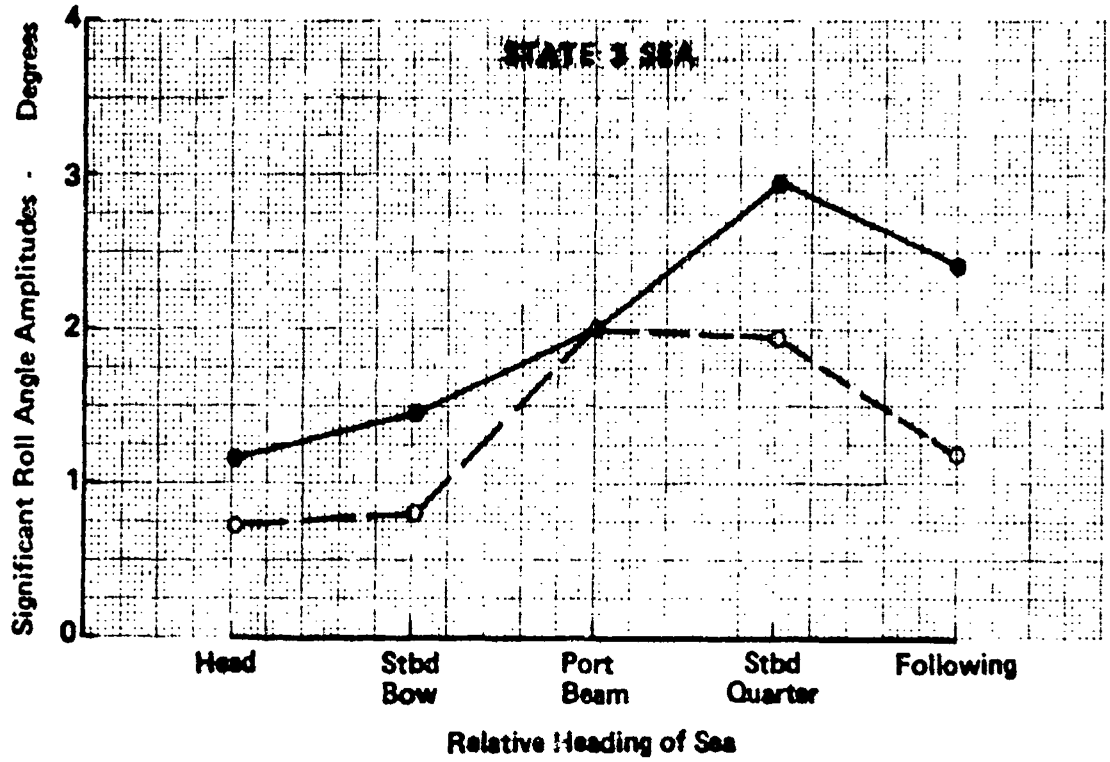


Figure 52 - Foilborne Rough Water Pitch Motions



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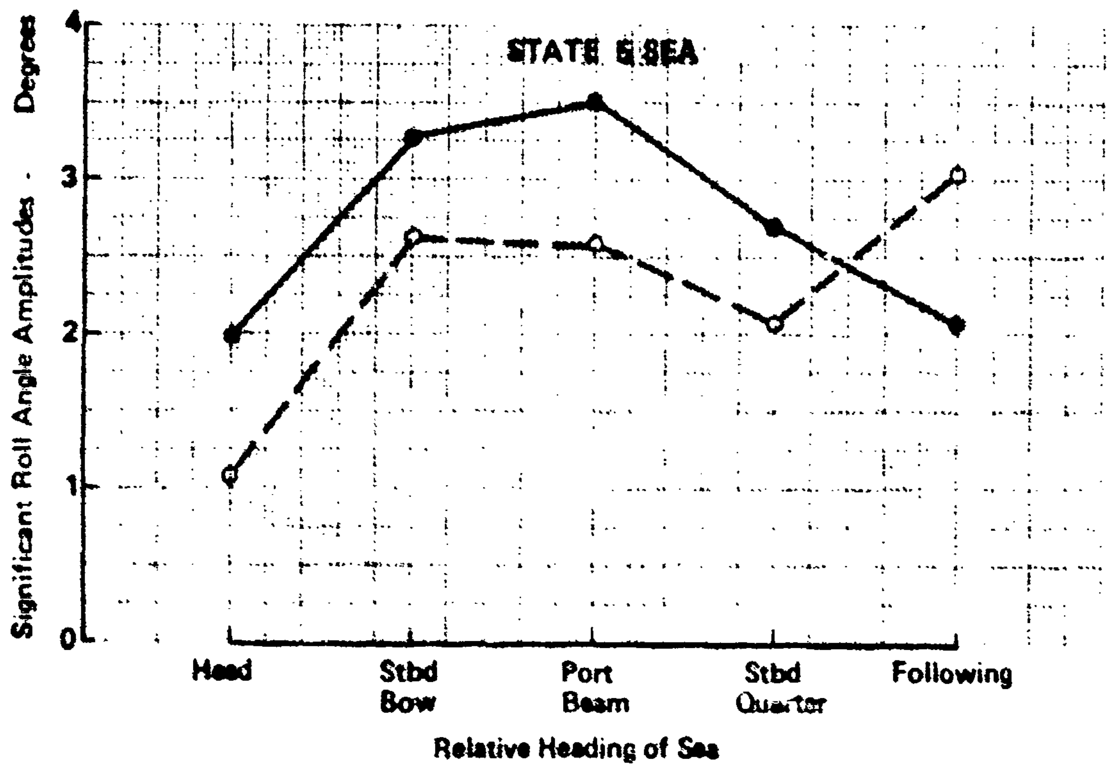


Figure 53 - Foilborne Rough Water Roll Motions

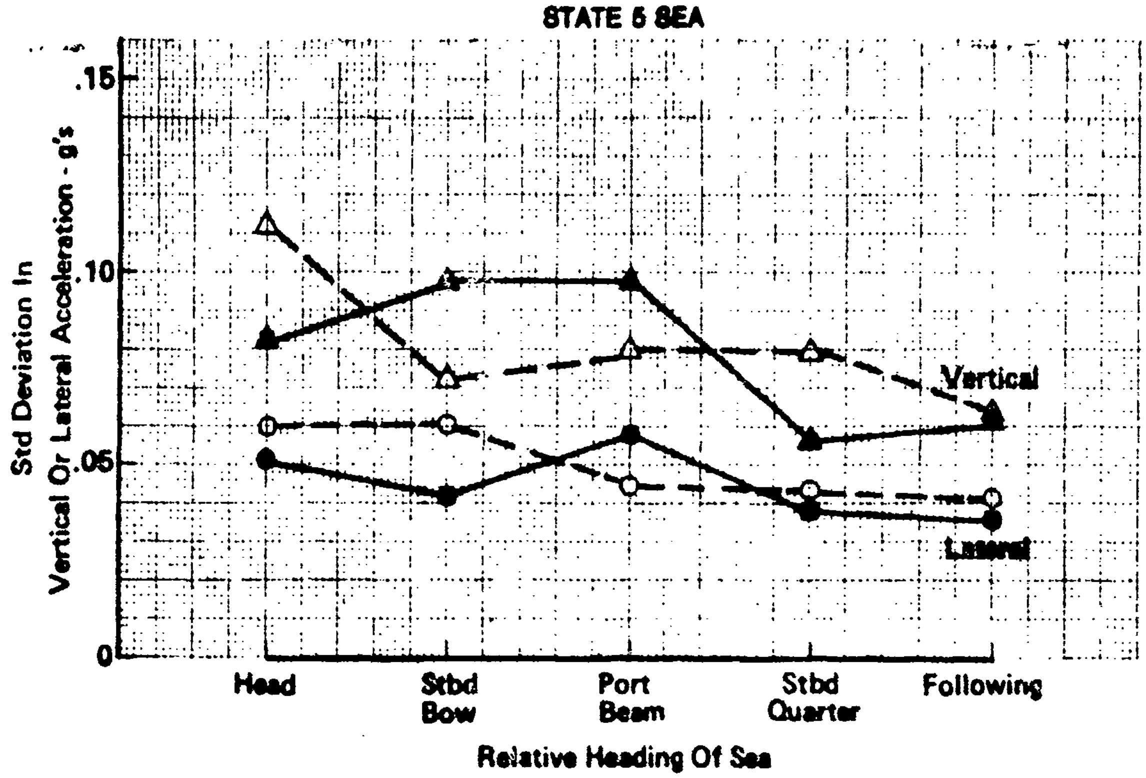
angle of 3 to 3.5 degrees which occurred with the SAS secured are quite small given the seas encountered. The SAS had the capability to reduce these angles by approximately 60 percent in the State 3 sea and 40 percent in State 5. The reversed position of the following sea data points in State 5 seas was confirmed in review of both sets of data. As noted earlier the ship failed to remain foilborne in the following State 5 sea tests with the SAS secured. The impact which the potential difference in test conditions may have on these last results is not known. Other numerical data pertinent to the roll test data are also included in Tables 16 through 19. Data traces of roll angle and wave height versus time during the State 3 and 5 beam sea conditions are given in Figures 64 and 65 in the Supportive Information Section.

The SAS was working to its full capacity during most of the State 5 matrix tests. During the port beam, starboard bow, and the following sea segments of this matrix the port and starboard flaps were fully deflected trailing edge down for extended periods of time.

Acceleration Amplitudes

During the State 3 and 5 trials vertical and lateral accelerations were recorded near the center of the lower forward cabin, under the bridge console in the pilothouse, and on the main deck, both near the CG and in the after section of the cabin. Surge accelerations were also recorded at the CG location. The data are presented as standard deviation values. The statistical 2.0x and 2.55x factors which can normally be used to estimate one-third and one-tenth highest average values from the standard deviation have not been applied in this report. This approach was considered inappropriate in this case where the shape of the test data distributions was not known.

The standard deviations in the lateral and vertical accelerations recorded near the CG of the RHS 200 during the State 3 and 5 trials are given in Figure 54. The data compare foilborne operation with and without SAS control. As discussed earlier, the State 5 sea data were derived from RTA data analysis. They are the average of 8 separate spectra taken over a three-minute interval. The State 3 sea data were derived through PSD analysis of a single spectra. The two sets of results are comparable in terms of overall levels. None of the data in



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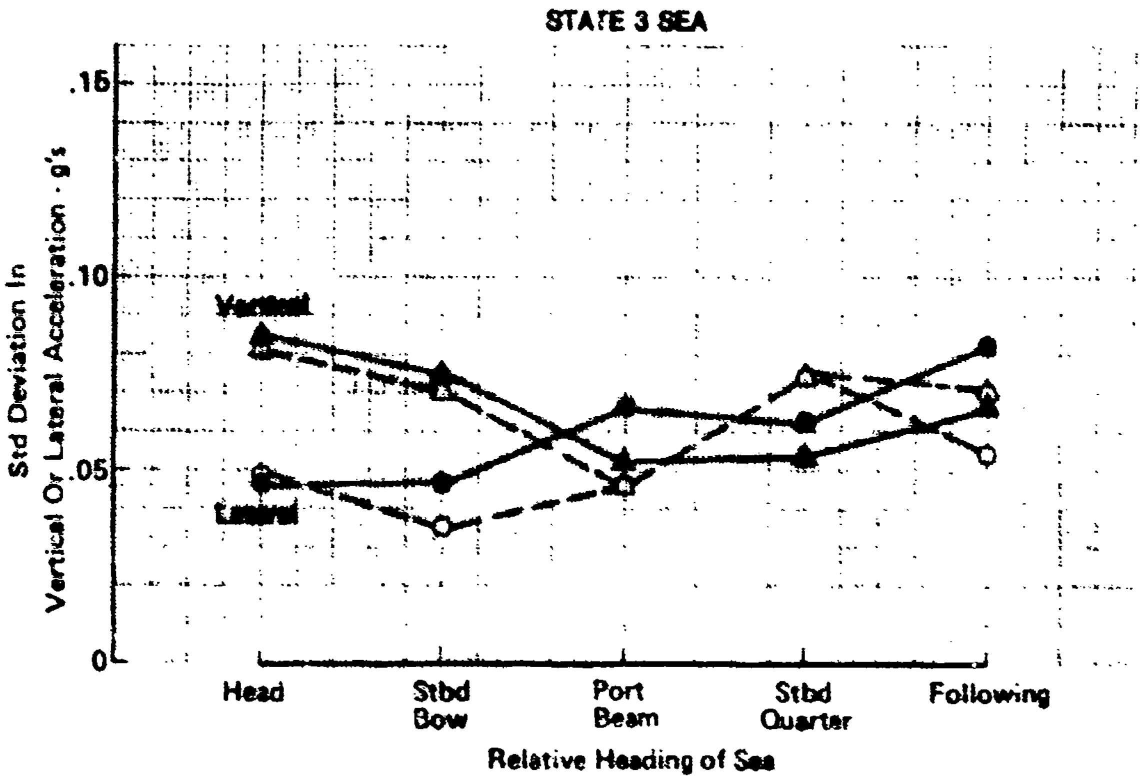


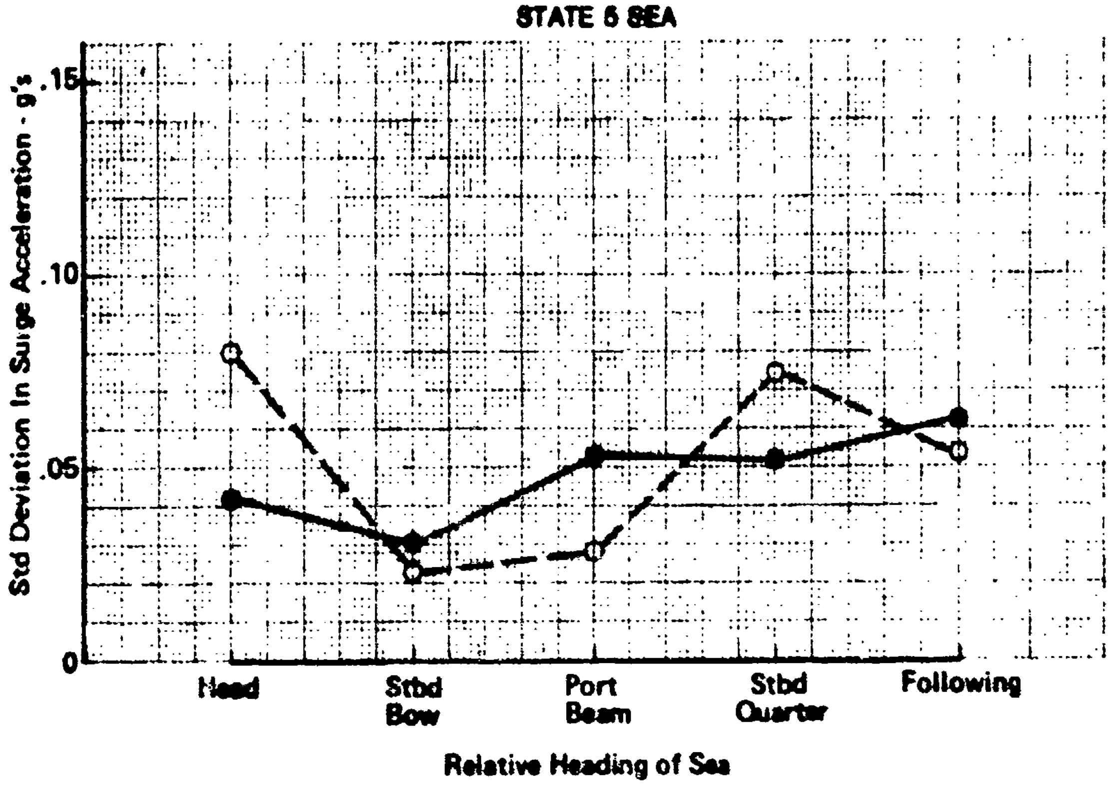
Figure 54 - Lateral and Vertical Accelerations at CG

the figure display trends which would indicate that the SAS has appreciable effect on the measured accelerations. In the State 3 tests the lateral and vertical accelerations are essentially equal for all cases except for the head and bow sea conditions. In the higher sea state the vertical accelerations were noticeably higher than the lateral. Tabular listings of the State 5 sea standard deviation data included in Figure 54 is given in Table 20 of the Supportive Information Section. A listing of all of the PSD derived acceleration data is given in Tables 21 through 26 of that section.

The surge accelerations recorded at the CG instrumentation package during the matrix trials are given in Figure 55. Again, the effect of the SAS is not clearly evident. The overall levels of the surge accelerations are much less than the lateral or vertical in State 3 seas. In State 5 seas the surge acceleration levels are more influenced by relative heading of the sea. They approach lateral and vertical acceleration levels in quartering and following sea conditions.

During normal operation of the RHS 200 the pilothouse is the only crew-manned operational station. The standard deviations of the vertical and lateral accelerations measured beneath the bridge console during the matrix trials are plotted in Figure 56. The State 3 seas lateral accelerations are approximately 50 percent greater than those recorded at the CG. The vertical accelerations in this sea are nearly double the values measured at the CG. In State 5 seas both the lateral and the vertical accelerations at the pilothouse are also nearly double those recorded at the CG. The sea state 5 bow and beam sea data indicate a reduction of approximately 25 percent in vertical acceleration levels with the use of the SAS. Data traces of lateral accelerations recorded on the bridge during beam State 5 seas operations are given in Figure 66 in the Supportive Information Section. Spectral distributions of the lateral and vertical accelerations at the pilothouse in head and beam State 5 seas are given in Figures 67 through 70 of that section.

The worst case accelerations recorded during the State 5 trials are plotted in Figure 57. The most severe lateral accelerations occurred in the aft lower passenger cabin where the average standard deviation in acceleration was 0.12g. The most severe vertical accelerations were recorded in the forward lower



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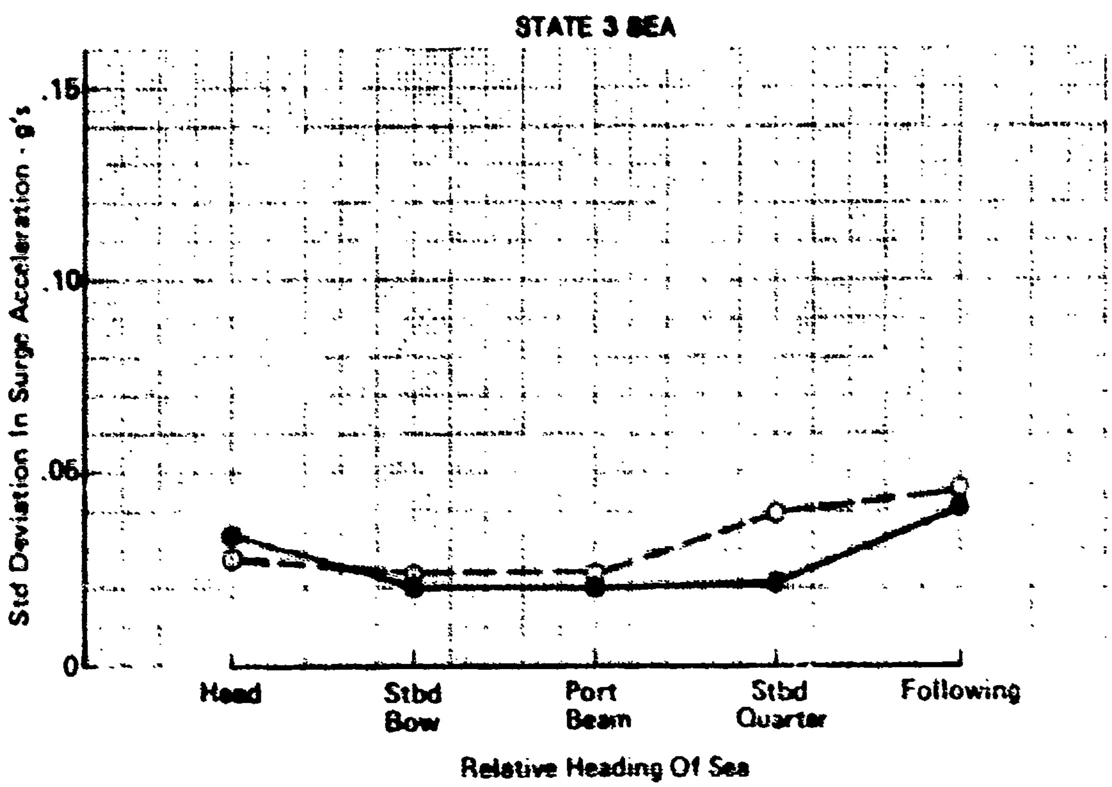
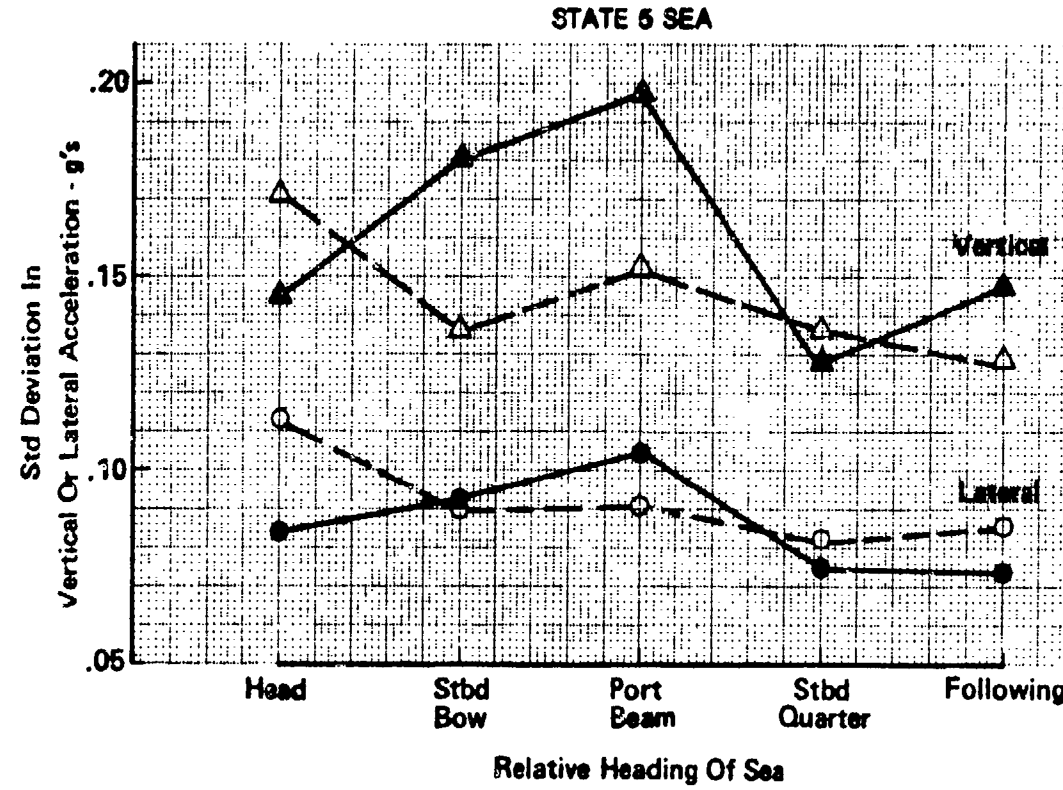


Figure 55 - Surge Accelerations at CG



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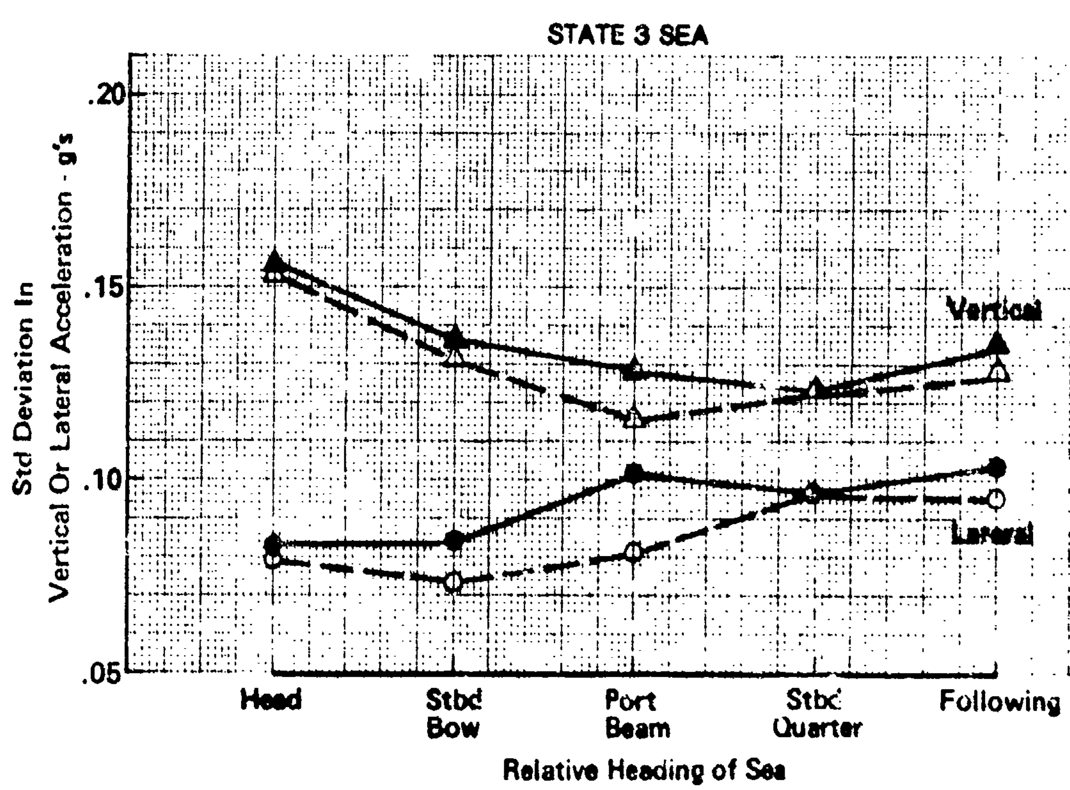
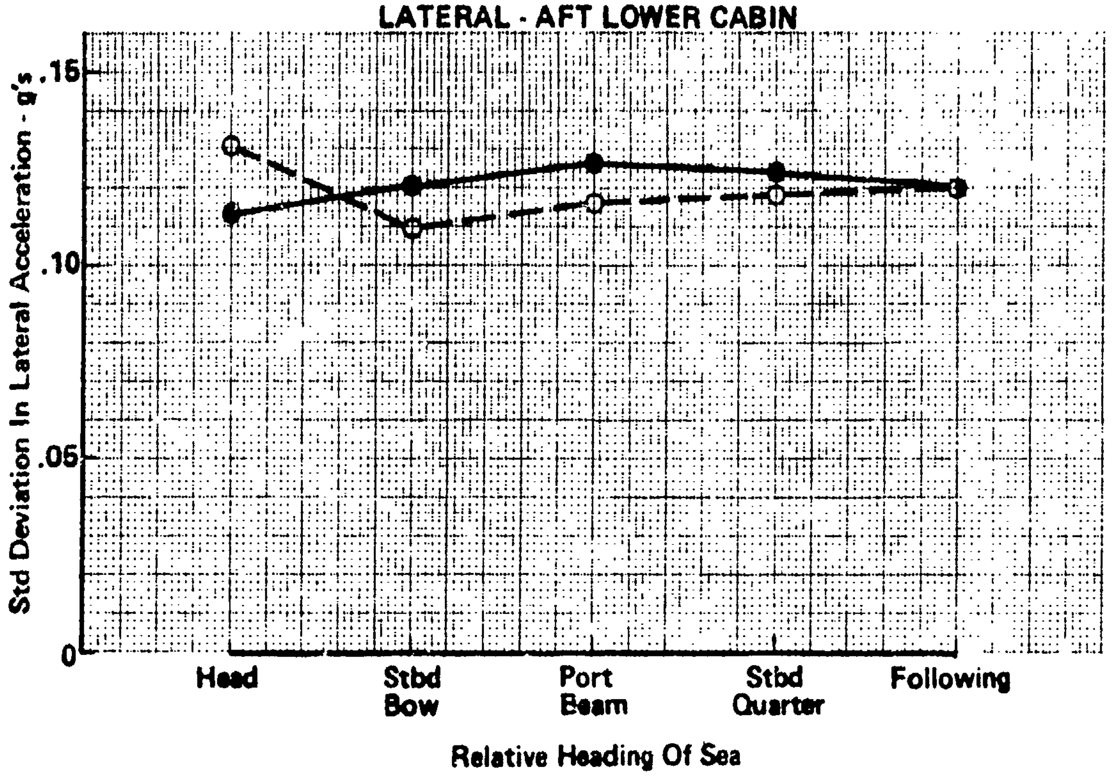


Figure 56 - Pilot House Lateral and Vertical Accelerations



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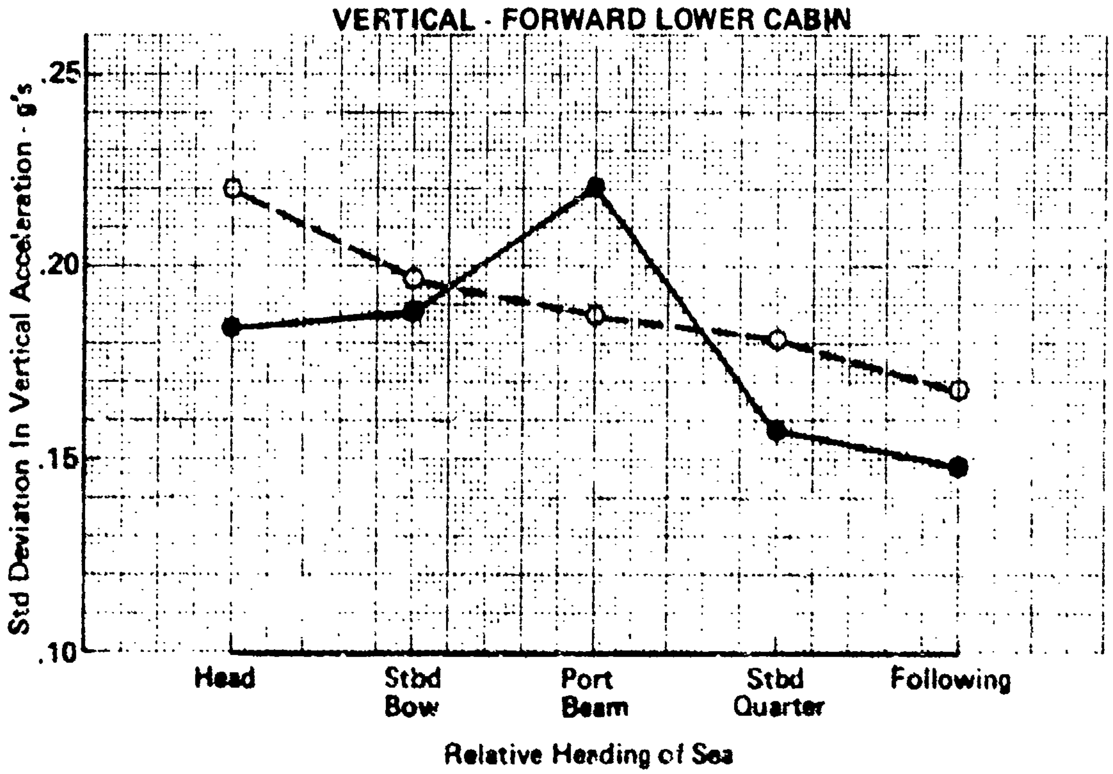


Figure 57 - Worst Case Accelerations in State 5 Seas

cabin. The maximum standard deviation was 0.22g. The SAS did not provide numerically significant improvement in these cases.

During the conduct of the State 5 sea matrix trials the ride was such that it was no longer possible to manually log information while standing at the chart table. Notes could be recorded while seated if the clipboard was held to the body. The Instrumentation Engineer recorded the same observation at the data station in the after section of the main deck cabin. In the physical sense there was a pronounced improvement in ride quality with the SAS in the Automatic mode. It is considered surprising that this improvement is not more clearly evident in the recorded data. A walk-through all of the passenger areas of the RHS 200 was made at this time. The transit was made single-handedly, without difficulty, using installed hand rails. A single-hand hold was required while standing. The pilothouse was judged to be the most physically comfortable locaiton. This judgement was influenced by reduced noise, better visibility, and position which was located above the sea. Only one encounter with sea sickness was noted. The individual concerned was able to fully resume his duties after only a brief respite.

Supportive Information

The data presented in this section was largely developed during the analysis of the rough water data. It may be of general or specific interests depending on the needs of the reader. Discussion of the material is primarily limited to its introduction.

Data traces of wave height and ship pitch during State 3 and 5 head and following seas are given in Figures 57 through 60. The test condition from which the traces were obtained and the starting time of the interval are identified in each data trace. The traces typically compare operation with the SAS in the Automatic mode and in the Manual mode. It was evident in the review of such data that individual ship responses were very dependent on the immediate wave train.

Typical flap motions recorded under head and following State 3 and 5 sea test conditions are given in Figures 61 and 62. A positive flap deflection denotes the flap trailing edge down, increased lift, condition. A reduced lift flap deflection bias is present in most of the data of these figures. The source

of the bias is unknown, it may result from trim adjustments input on the SAS Control Panel.

Roll response data traces for operation in State 3 and 5 beam seas are given in Figures 63 and 64. The effectiveness of the SAS in State 3 seas is clearly evident. In State 5 seas the flaps did not have sufficient authority to limit ship roll under the influence of the larger, lower frequency waves.

Typical forward cabin and pilothouse accelerometer traces in State 5 seas are given in Figure 65. The distinctive stepped pattern within the data is due to the digital sampling rate, 20 samples per second, used with these measurands in the data acquisition system.

Typical spectra derived from RTA analysis of the pilothouse lateral and vertical accelerations are given in Figures 66 through 69. Each plot is the average of 8 separate spectra taken with an upper frequency cutoff of 10 Hz. The repeatability of such analysis is demonstrated by a comparison of test 17A1 data given in Figures 67 and 69. Both of these spectra were taken over the same data interval under identical analysis commands. The source of the acceleration peaks at 4.75 and 5.45 Hz noted in these and other plots has not been identified.

Tables 16 through 29 list the principal numerical results obtained in analysis of the manual histograms for wave height, pitch angle, and roll angle during the rough water tests. PSD derived functions of yaw rate during the matrix trials is included in Tables 16 and 17. This latter information has not been considered beyond this listing due to the magnitude of the yaw rate correction discussed in the section on Data Reduction.

A numerical summary of the Standard deviations in acceleration derived through RTA analysis is given in Table 20. The summary results of all of the data submitted to PSD analysis is given in Tables 21 through 24.

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

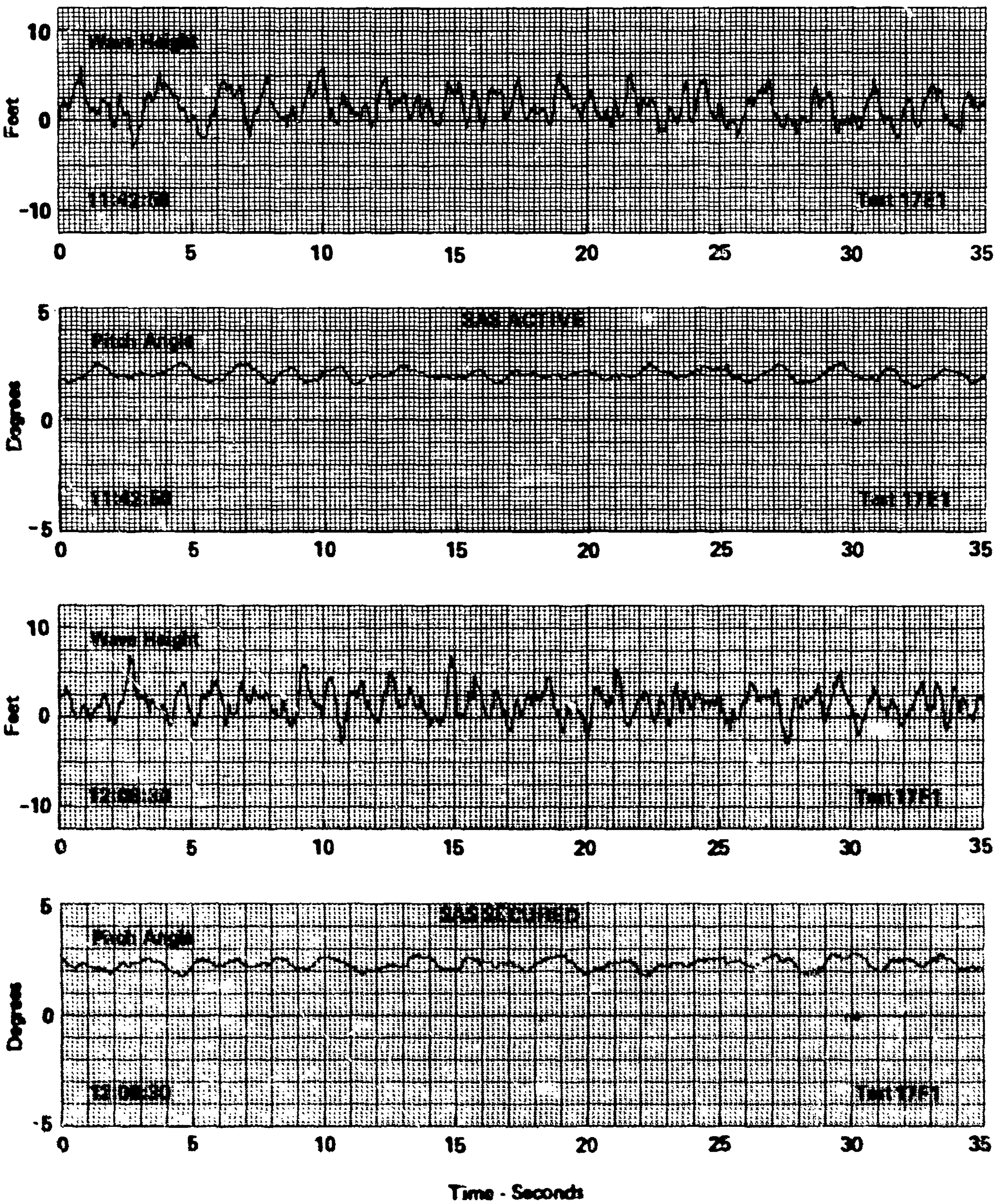


Figure 58 - Pitch Response in State 3 Head Seas

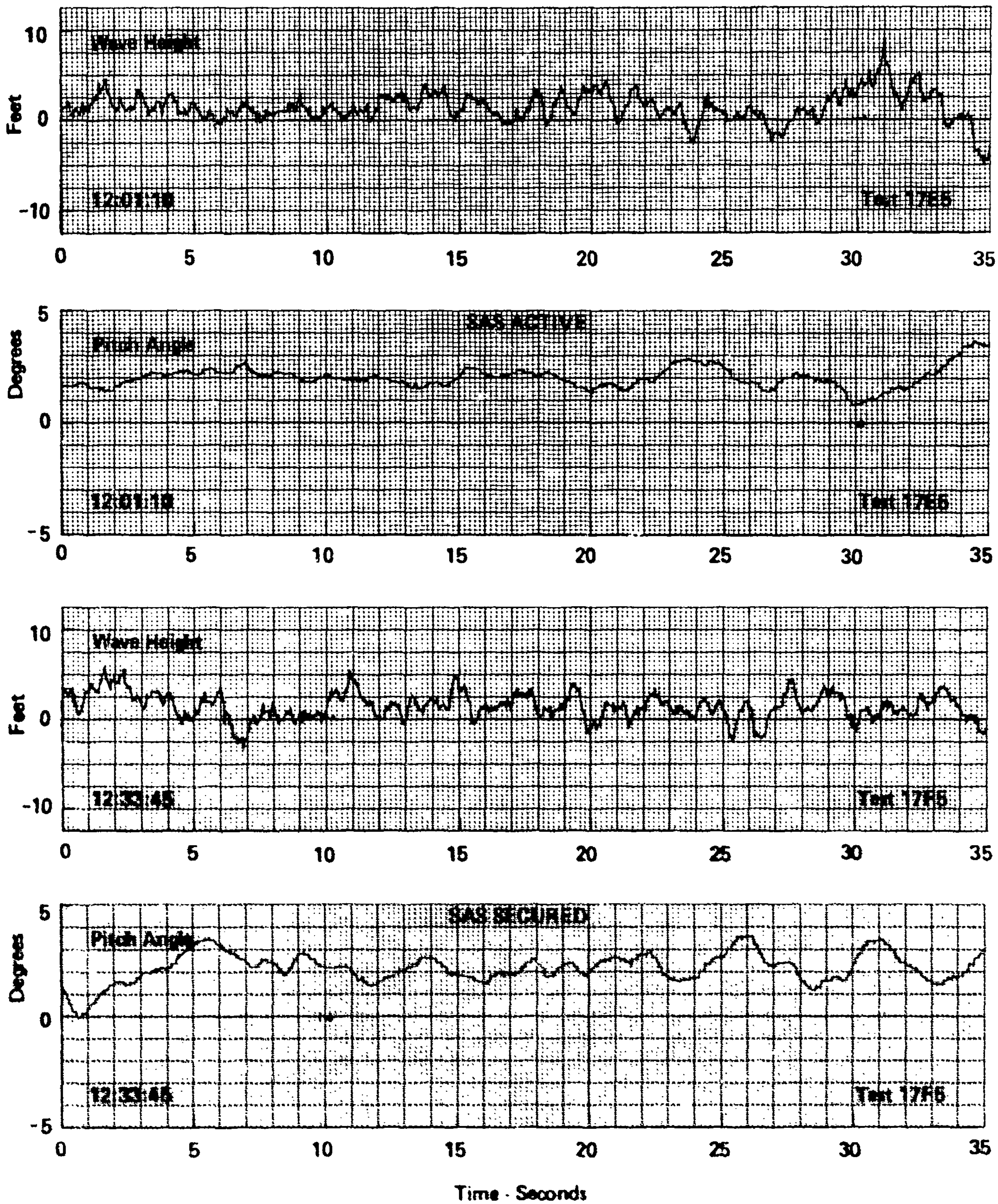


Figure 59 - Pitch Response in State 3 Following Seas

RHS 200 PERFORMANCE EVALUATION - APRIL 1982

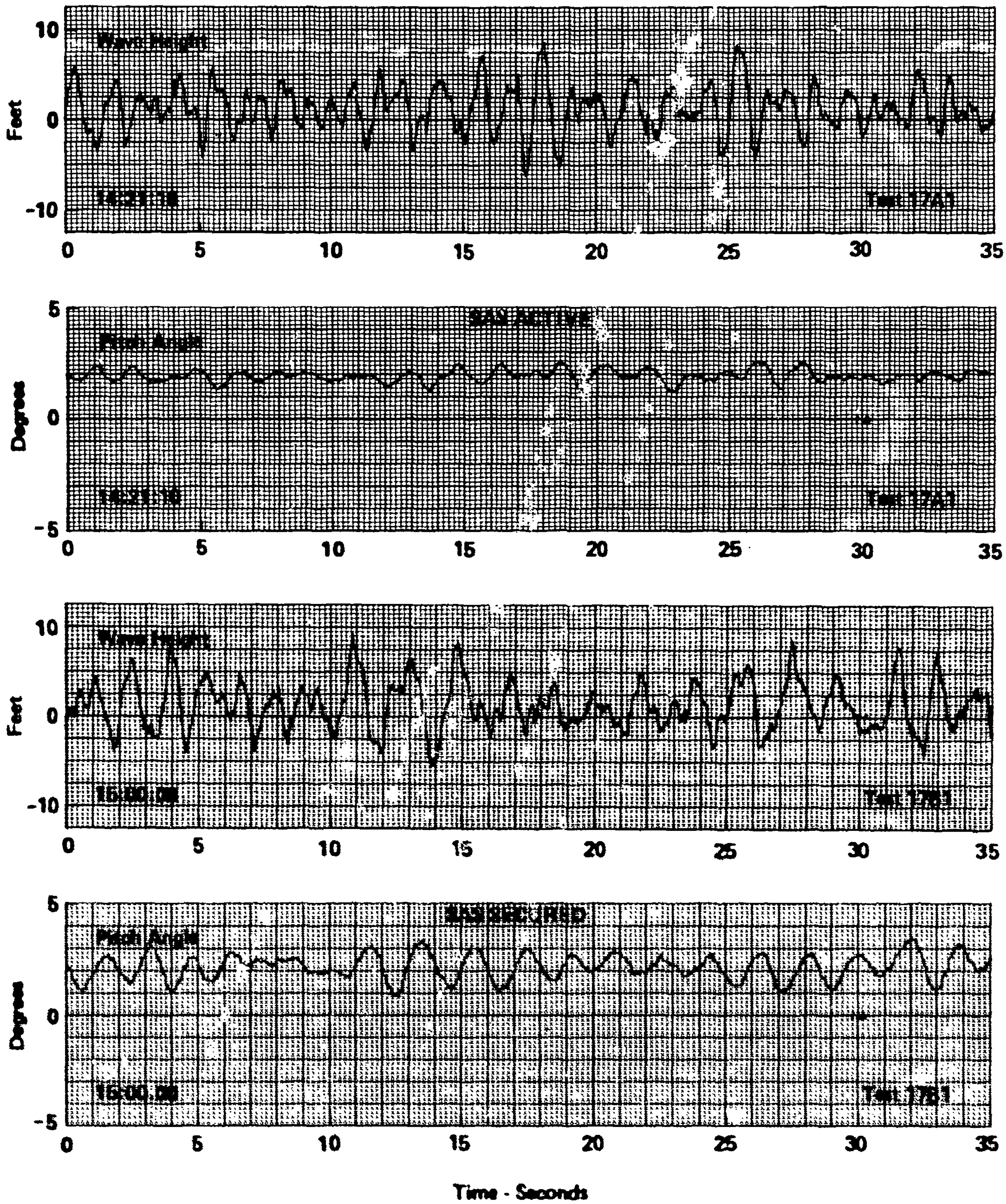


Figure 60 - Pitch Response in State 5 Head Seas

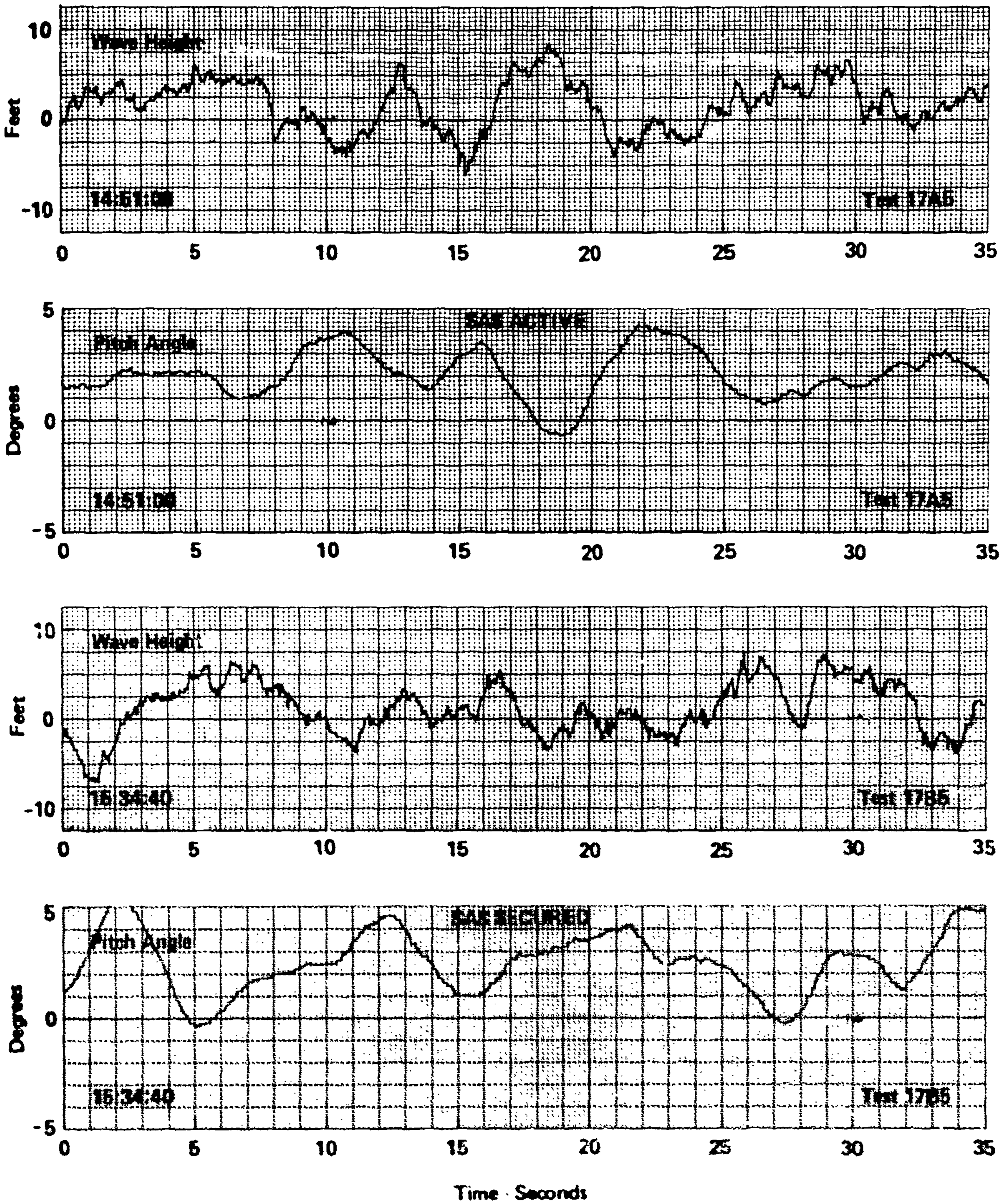


Figure 61 - Pitch Response in State 5 Following Seas

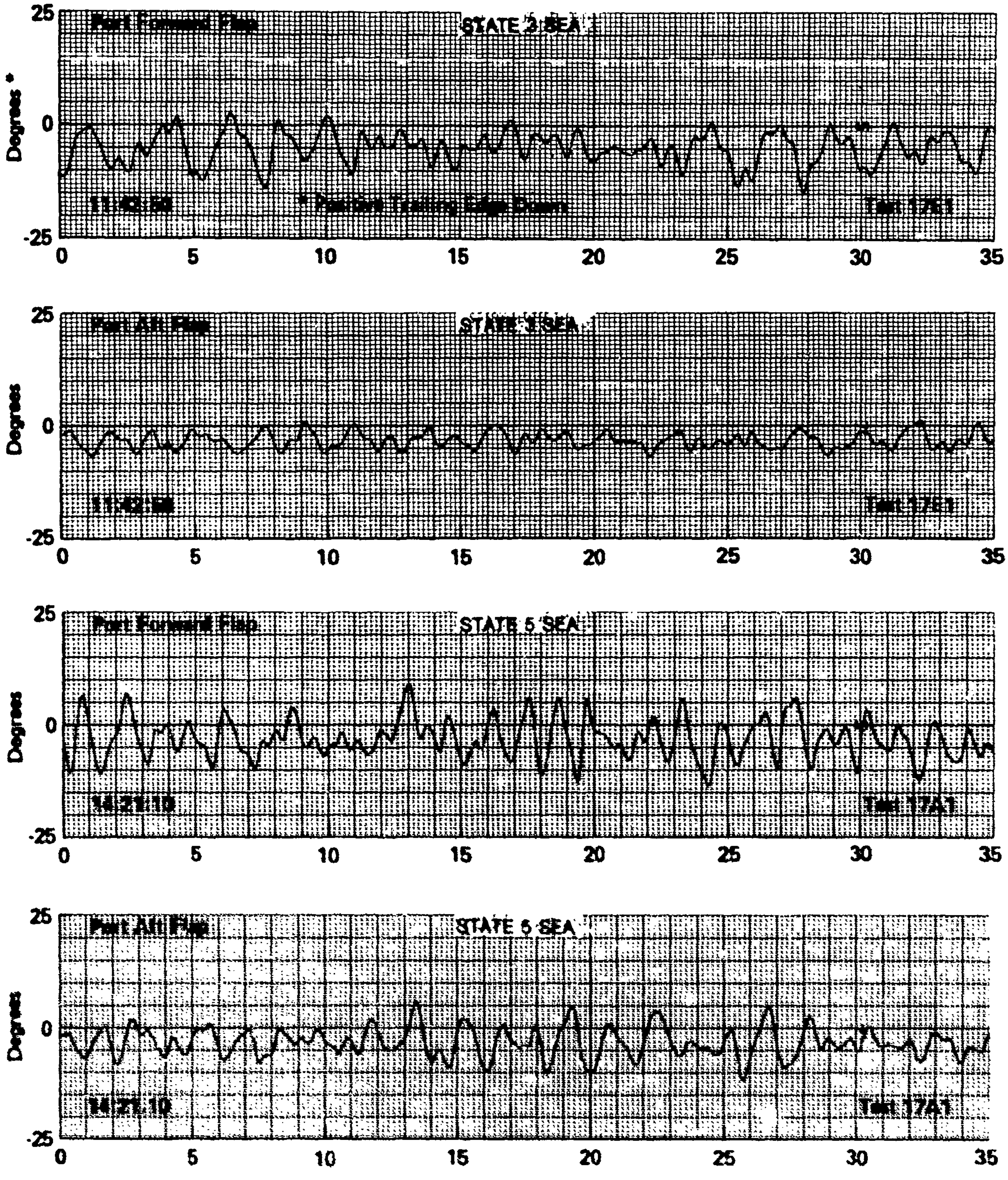


Figure 62 - Flap Motions Under Head Sea Conditions

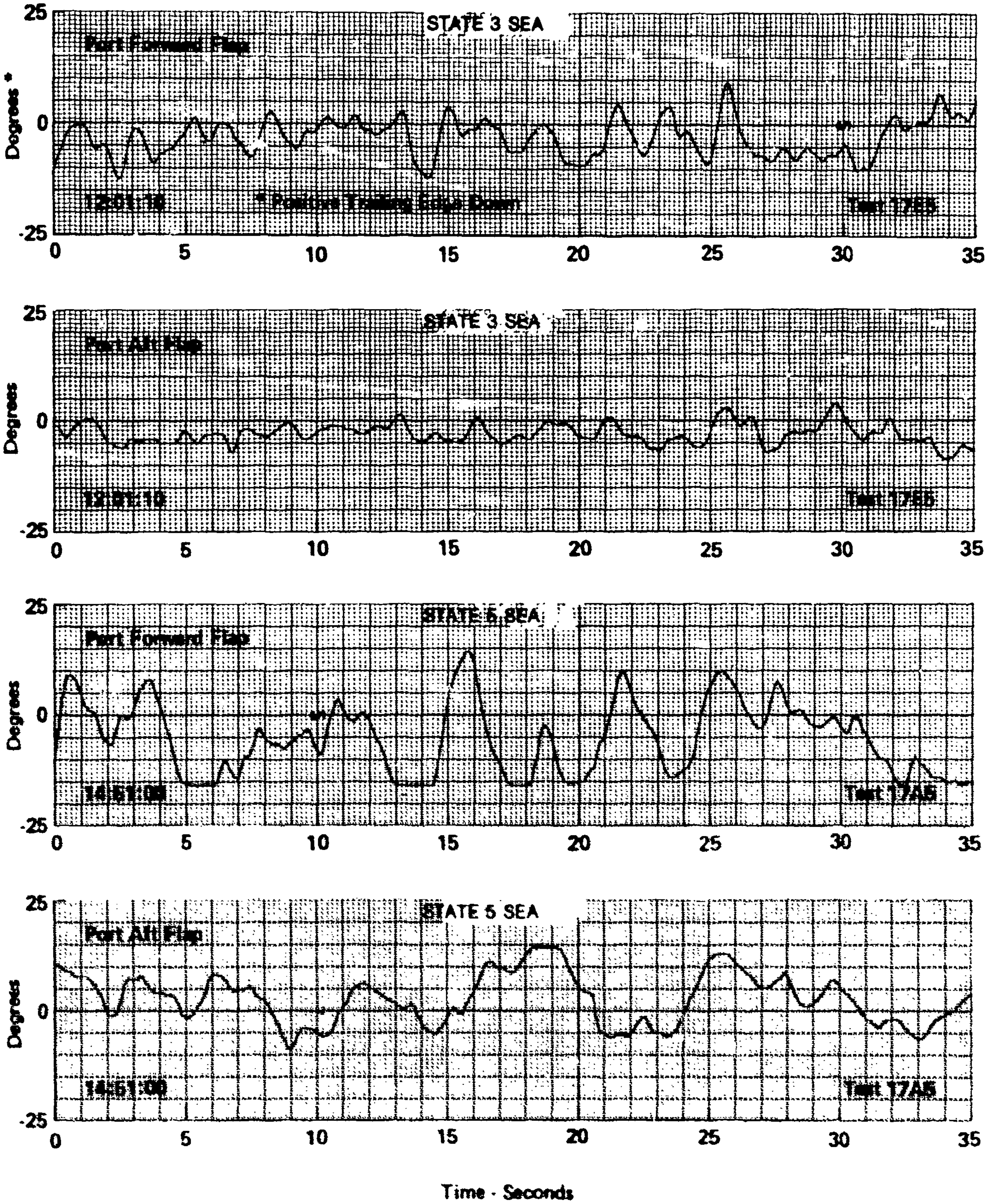


Figure 63 - Flap Motions Under Following Sea Conditions

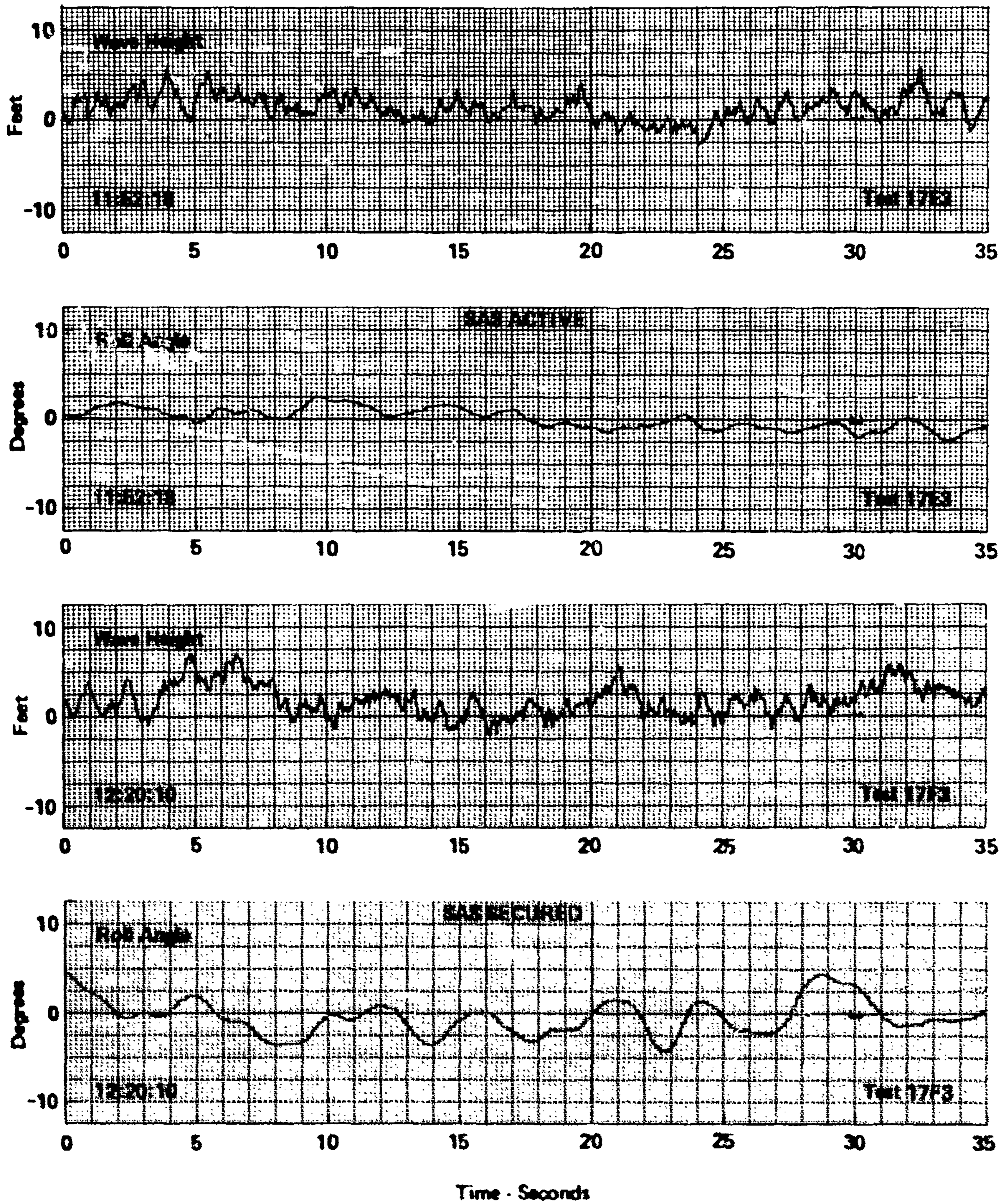


Figure 64 - Roll Response in State 3 Port Beam Seas

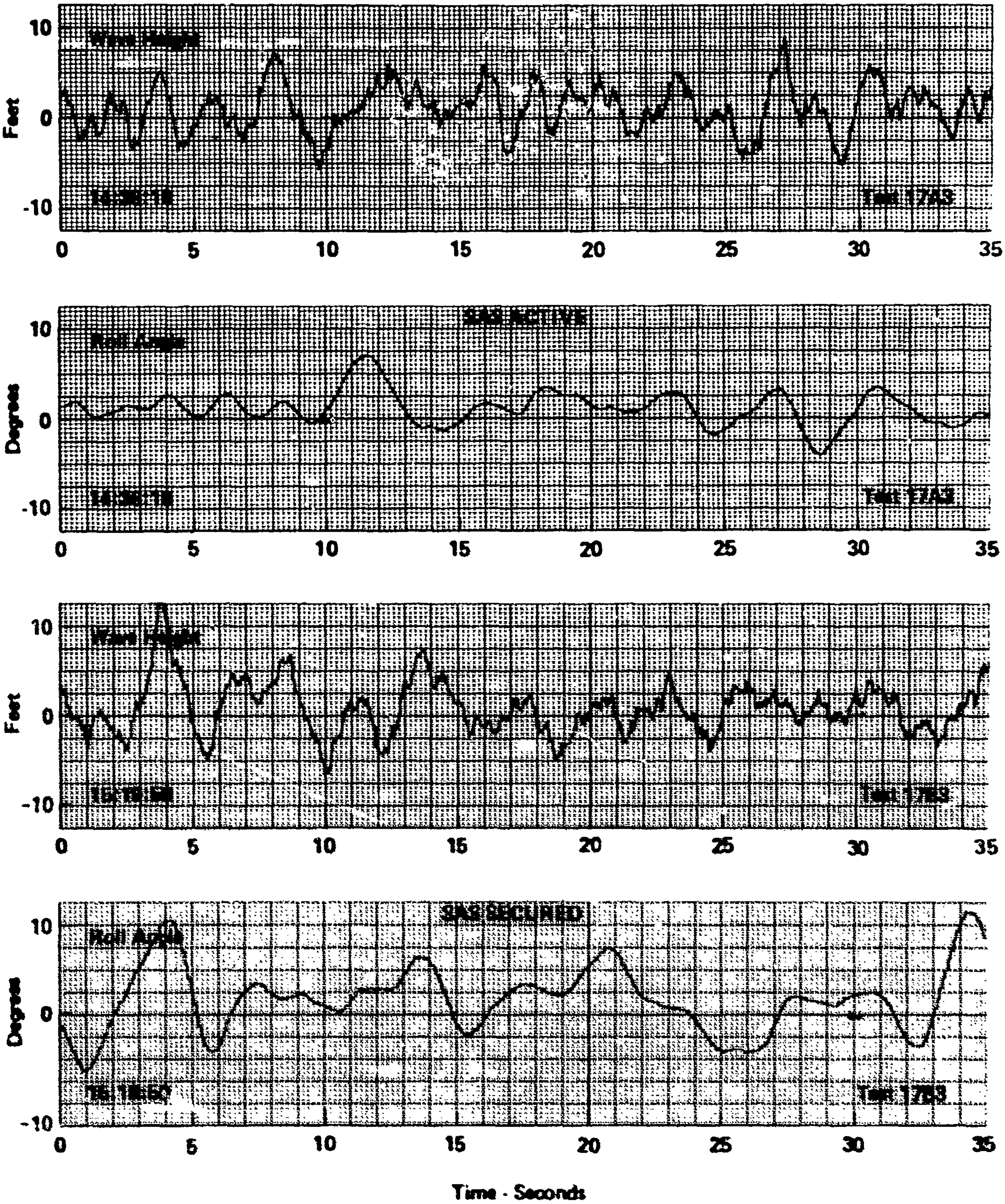


Figure 65 - Roll Response in State 5 Port Beam Seas

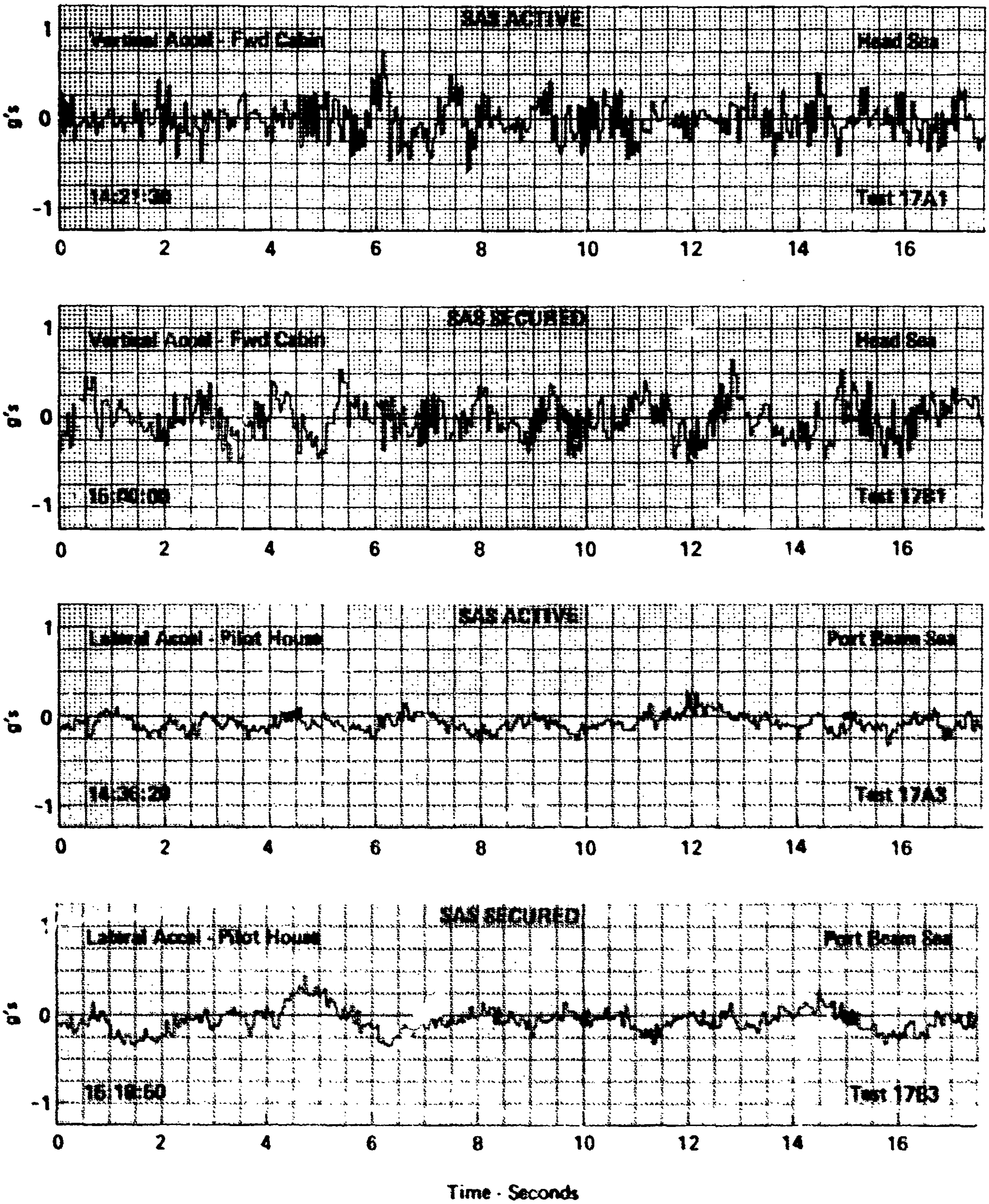
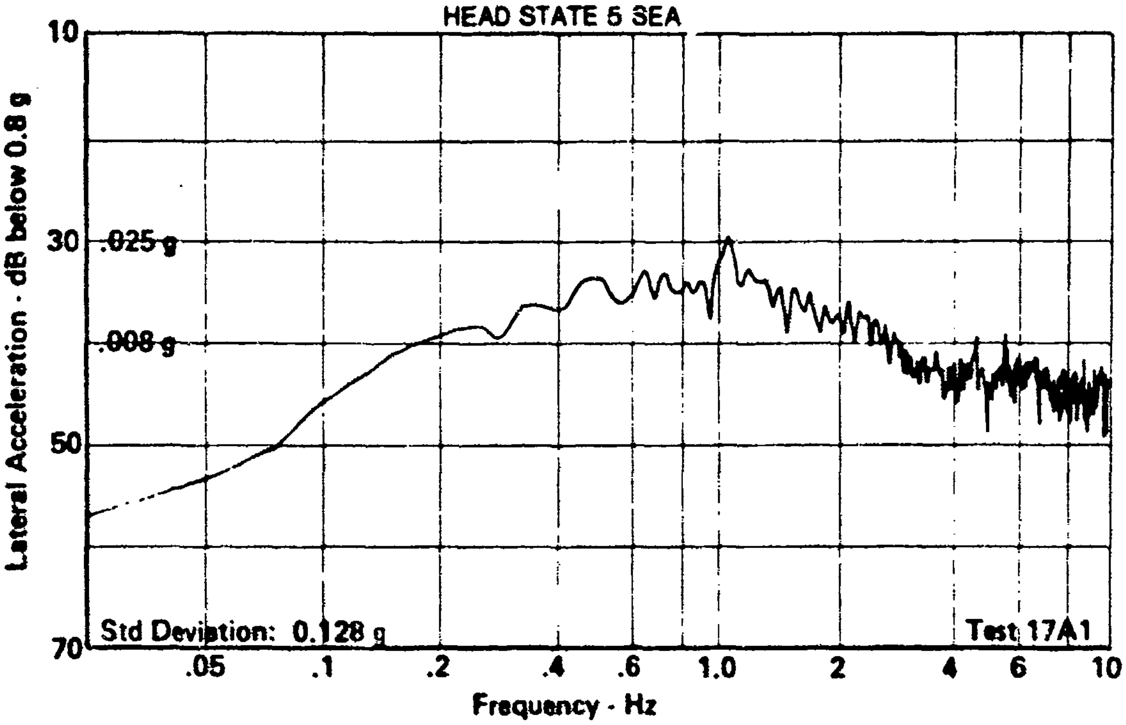


Figure 66 - Typical State 5 Seas Accelerometer Traces



SAS ACTIVE

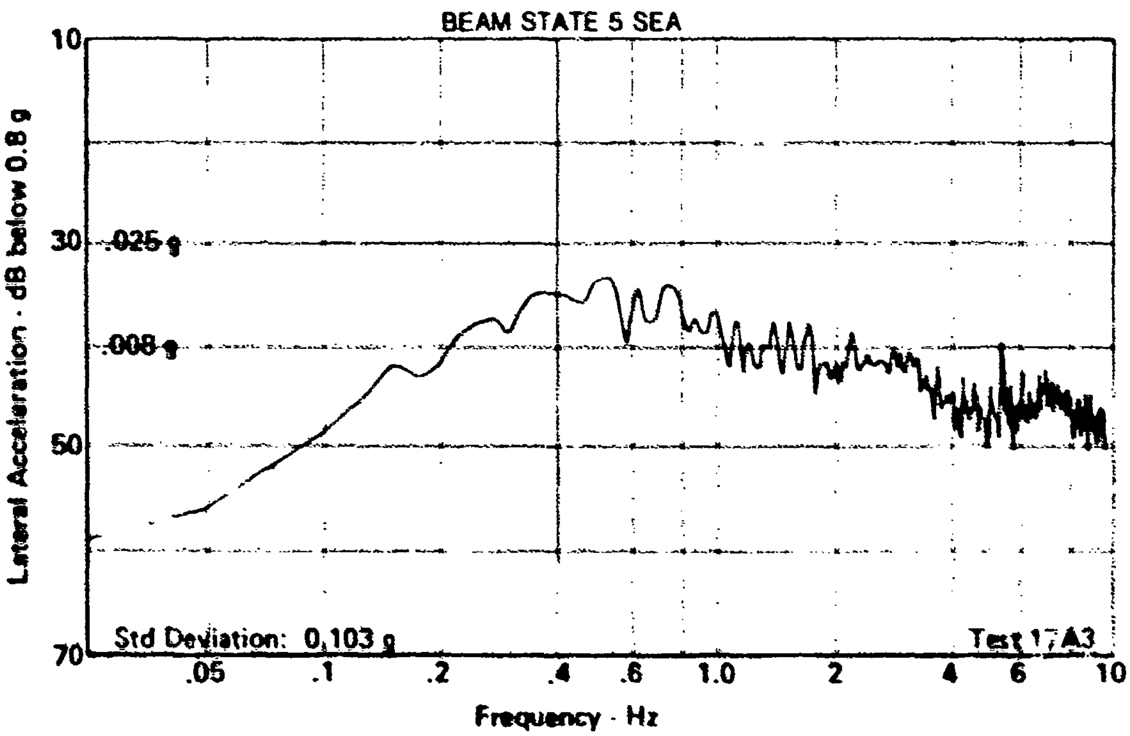
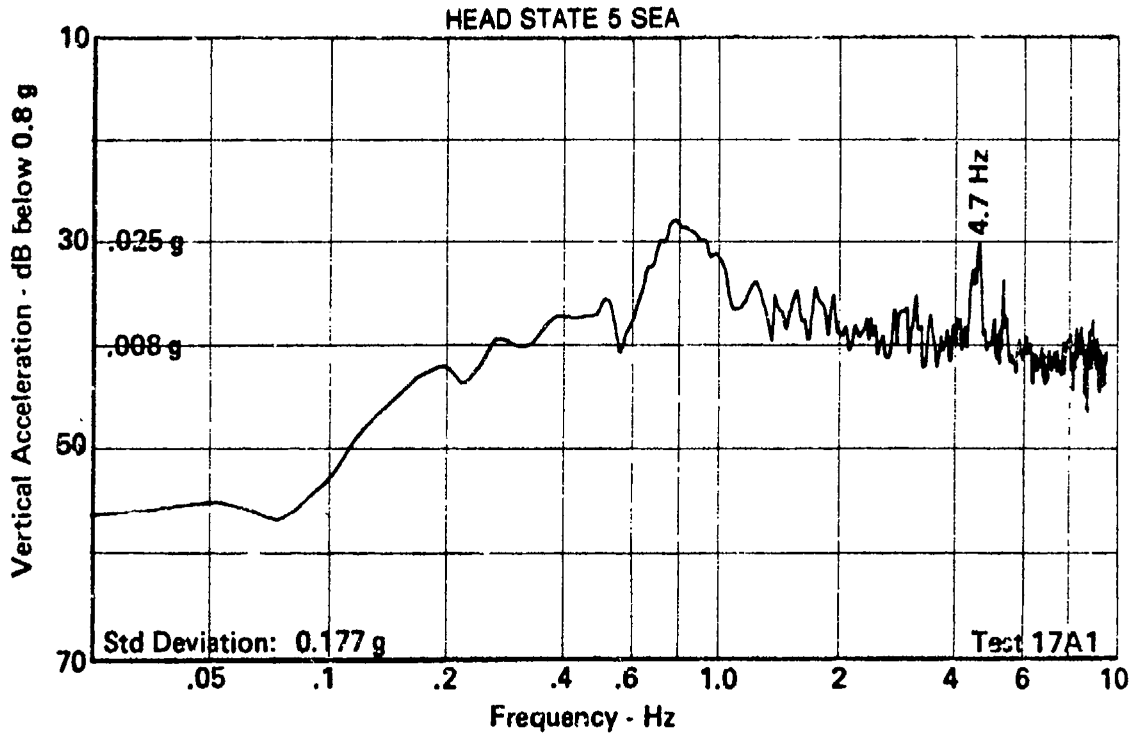


Figure 67 - Pilot House Lateral Acceleration Spectra



SAS ACTIVE

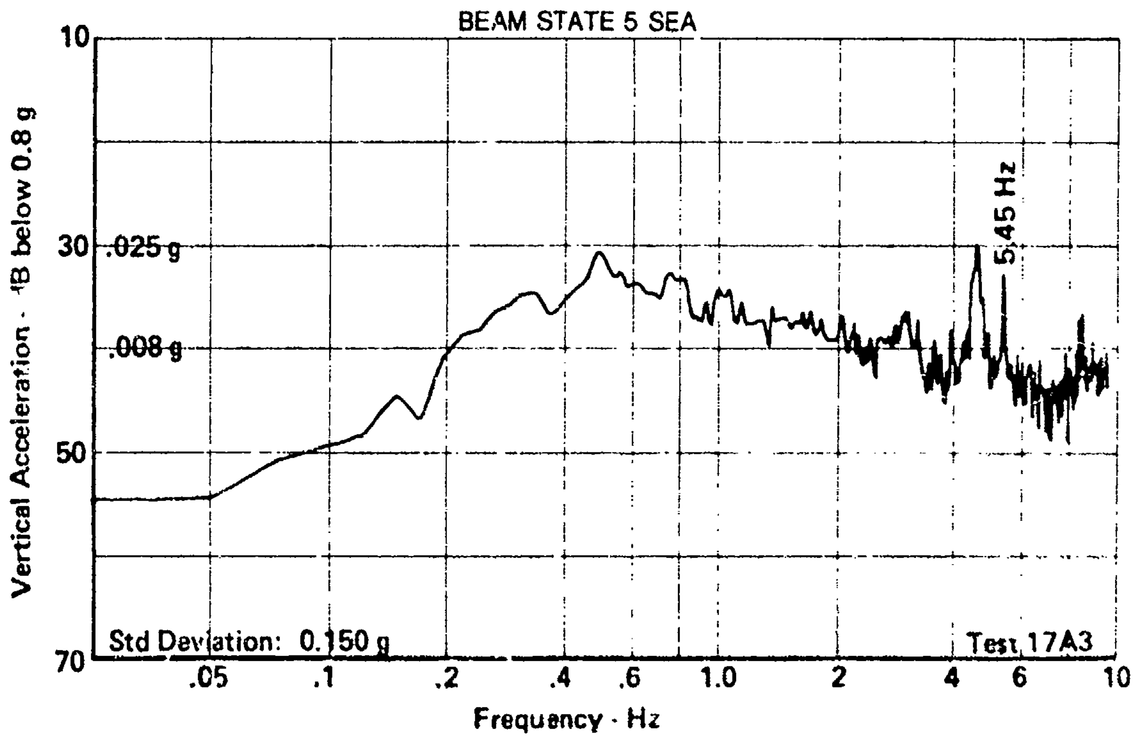
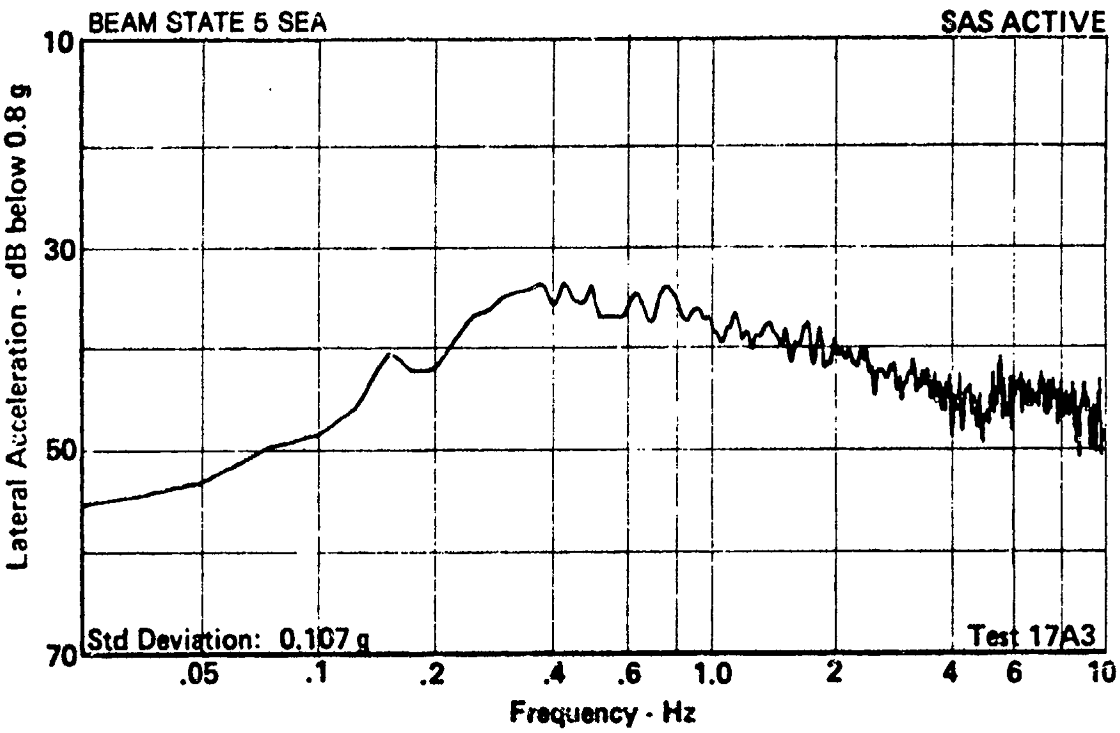


Figure 68 - Pilot House Vertical Acceleration Spectra



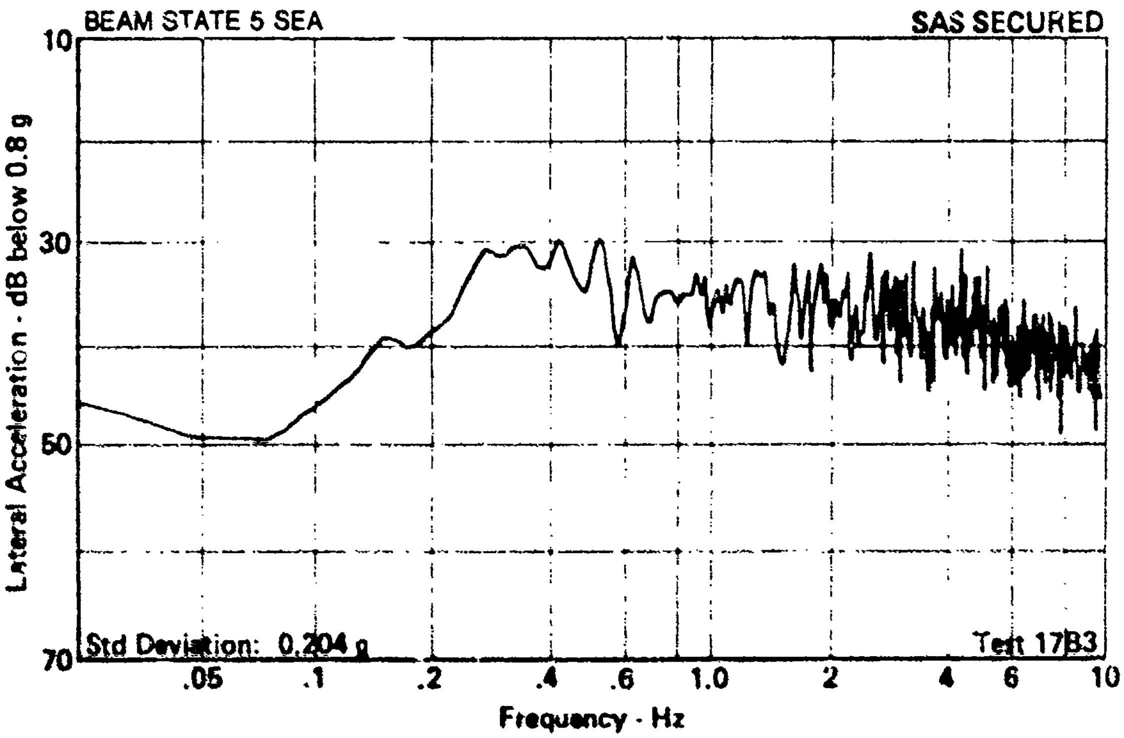
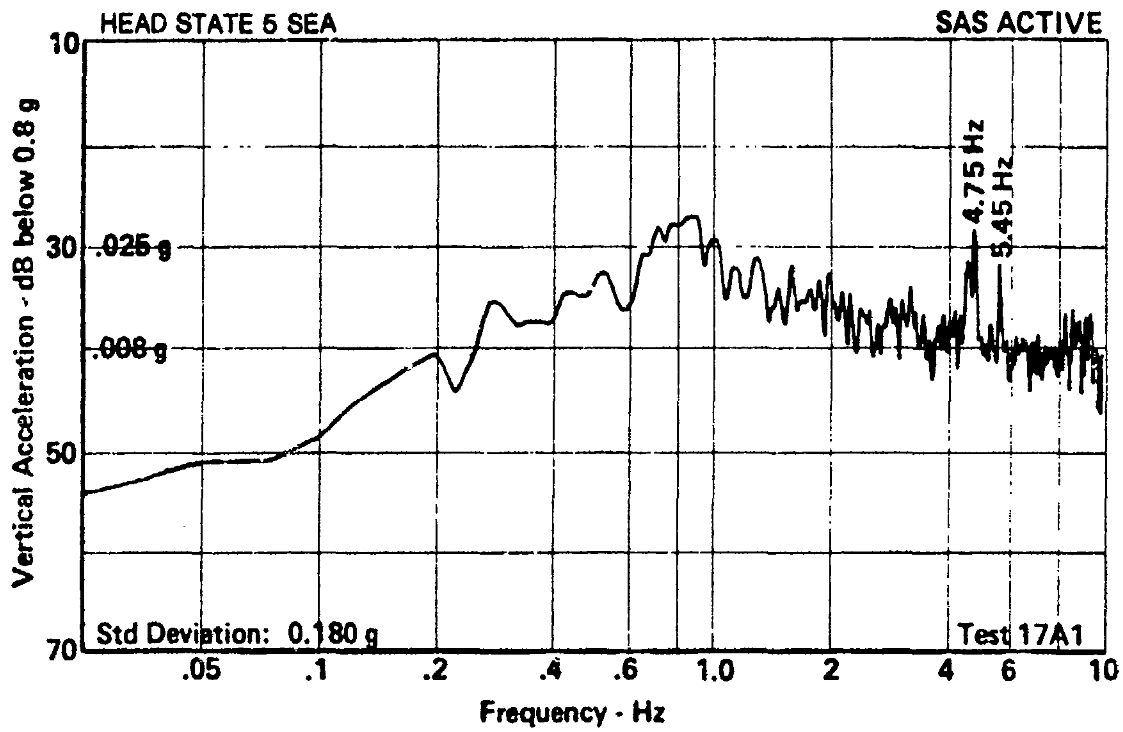


Figure 69 - Pilot House Lateral Acceleration Spectra - Effect of SAS



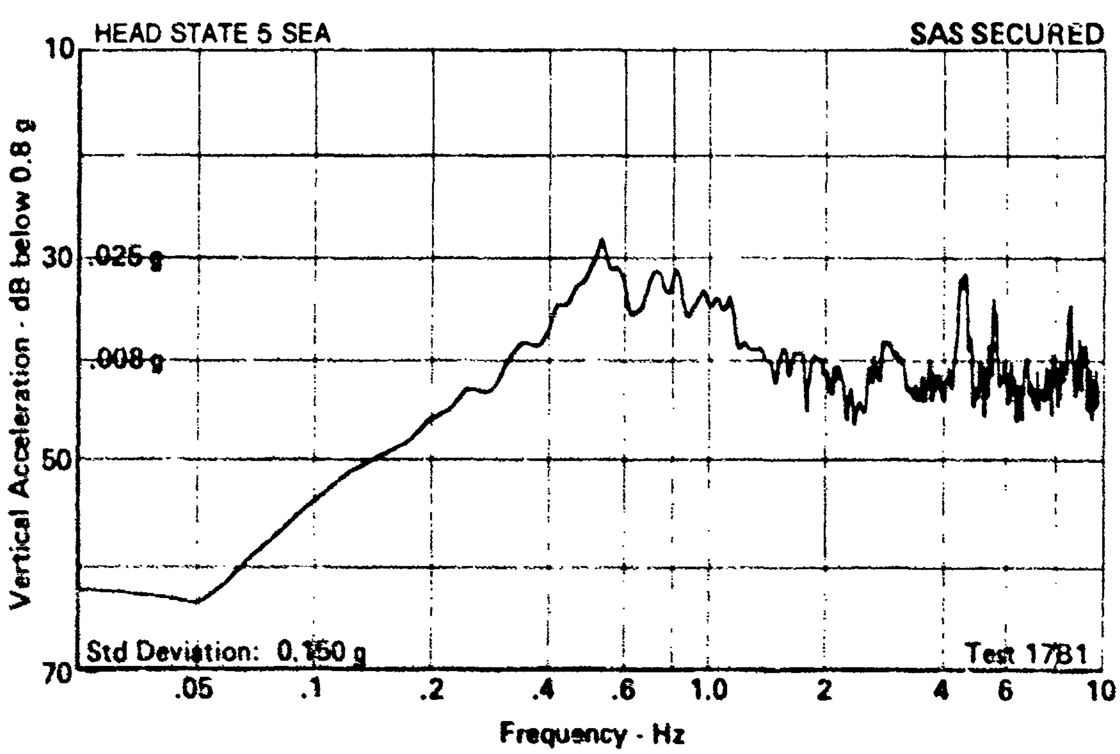


Figure 70 - Pilot House Vertical Acceleration Spectra - Effect of SAS

TABLE 16 - ROUGH WATER MOTIONS - MEAN AMPLITUDES

	WAVE HEIGHT	PITCH ANGLE	ROLL ANGLE	YAW* RATE
Foilborne in State 3 Sea: SAS Active				
17e1 Head Sea	1.799	2.112	-1.463	0.289
17e4 Stbd Bow	1.782	2.170	-1.782	0.254
17e3 Port Beam	1.530	1.947	-0.120	0.445
17e2 Stbd Qtr	1.641	2.166	-1.275	0.469
17e5 Following	1.746	2.108	-0.789	0.309
Foilborne In State 3 Sea: SAS Secured				
17f1 Head Sea	1.705	2.325	-2.315	0.091
17f4 Stbd Bow	1.914	2.390	-2.640	0.253
17f3 Port Beam	1.598	2.456	-2.014	0.199
17f2 Stbd Qtr	1.402	2.189	-2.039	0.267
17f5 Following	1.667	2.326	-1.162	0.213
Foilborne In State 5 Sea: SAS Active				
17a1 Head Sea	2.767	1.892	-1.393	0.249
17a4 Stbd Bow	2.333	2.218	-1.510	0.184
17a3 Port Beam	3.103	1.948	0.297	0.245
17a2 Stbd Qtr	2.445	2.014	-1.447	0.314
17a5 Following	2.555	2.289	-0.273	0.290
Foilborne In State 5 Sea: SAS Active				
17b1 Head Sea	2.674	2.230	-0.790	0.193
17b4 Stbd Bow	3.501	2.215	-1.570	0.213
17b3 Port Beam	3.493	2.143	0.817	0.278
17b2 Stbd Qtr	2.441	2.278	-0.836	0.210
17b5 Following	2.854	2.476	-0.552	0.248
Hullborne In State 3 Sea: SAS Secured				
15b1 Head Sea	1.376	1.708	-1.918	0.217
15b4 Stbd Bow	1.610*	1.713	-3.015	0.248
15b3 Port Beam	1.198*	1.661	0.731	0.146
15b2 Stbd Qtr	1.251*	1.468	-2.110	0.223
15b5 Following	1.269*	2.055	-1.551	0.248
DIW For Sea Kindliness				
Initial Head Sea	1.716	0.935	-2.114	

*Derived from Power Spectural Density analysis

TABLE 17 - ROUGH WATER MOTIONS - STANDARD DEVIATIONS IN AMPLITUDE

	WAVE HEIGHT	PITCH ANGLE	ROLL ANGLE	YAW* RATE
Foilborne In State 3 Sea: SAS Active				
17e1 Head Sea	1.839	0.311	0.511	0.560
17e4 Stbd Bow	2.135	0.339	0.559	0.553
17e3 Port Beam	1.975	0.589	1.342	0.779
17e2 Stbd Qtr	2.025	0.519	1.326	0.916
17e5 Following	2.159	0.532	0.842	0.753
Foilborne In State 3 Sea: SAS Secured				
17f1 Head Sea	1.627	0.309	0.774	0.458
17f4 Stbd Bow	2.293	0.424	0.983	0.565
17f3 Port Beam	1.947	0.659	1.339	0.806
17f2 Stbd Qtr	1.712	0.573	1.966	0.525
17f5 Following	2.041	0.773	1.616	0.650
Foilborne In State 5 Sea: SAS Active				
17a1 Head Sea	2.702	0.345	0.702	1.161
17a4 Stbd Bow	2.763	0.573	1.750	1.185
17a3 Port Beam	3.661	0.664	1.707	0.973
17a2 Stbd Qtr	2.918	0.666	1.375	0.815
17a5 Following	3.191	1.021	1.842	1.020
Foilborne In State 5 Sea: SAS Secured				
17b1 Head Sea	3.266	0.644	1.343	0.803
17b4 Stbd Bow	4.112	0.954	2.205	0.880
17b3 Port Beam	4.075	0.874	2.353	1.078
17b2 Stbd Qtr	3.041	1.184	1.830	0.728
17b5 Following	3.555	1.529	1.356	0.930
Hullborne In State 3 Sea: SAS Secured				
15b1 Head Sea	1.475	0.562	0.451	0.471
15b4 Stbd Bow	1.726*	0.594	0.629	0.468
15b3 Port Beam	1.285*	0.774	2.333	0.589
15b2 Stbd Qtr	1.341*	0.409	1.834	0.606
15b5 Following	1.360*	0.971	1.779	0.677
DIW For Sea Kindliness				
Initial Head Sea	1.622	.758	1.273	

*Derived from Power Spectural Density analysis

TABLE 18 - ROUGH WATER MOTIONS - SIGNIFICANT AMPLITUDES

	WAVE HEIGHT	PITCH ANGLE	ROLL ANGLE
Foilborne In State 3 Sea: SAS Active			
17e1 Head Sea	2.848	0.465	0.747
17e4 Stbd Bow	3.116	0.496	0.827
17e3 Port Beam	2.667	0.858	2.027
17e2 Stbd Qtr	2.987	0.779	1.960
17e5 Following	3.186	0.783	1.237
Foilborne In State 3 Sea: SAS Secured			
17f1 Head Sea	2.600	0.458	1.169
17f4 Stbd Bow	3.344	0.656	1.455
17f3 Port Beam	2.886	0.912	2.009
17f2 Stbd Qtr	2.498	0.851	2.993
17f5 Following	2.998	1.158	2.447
Foilborne In State 5 Sea: SAS Active			
17a1 Head Sea	4.382	0.503	1.033
17a4 Stbd Bow	4.205	0.847	2.615
17a3 Port Beam	5.091	0.987	2.597
17a2 Stbd Qtr	4.278	0.981	2.095
17a5 Following	4.829	1.546	3.053
Foilborne In State 5 Sea: SAS Secured			
17b1 Head Sea	4.583	0.941	1.995
17b4 Stbd Bow	6.204	1.394	3.292
17b3 Port Beam	5.867	1.285	3.50
17b2 Stbd Qtr	4.610	1.764	2.713
17b5 Following	5.265	2.306	2.099
Hullborne In State 3 Sea: SAS Secured			
15b1 Head Sea	2.229	0.860	0.656
15b4 Stbd Bow	2.609	0.870	0.939
15b3 Port Beam	1.941	1.170	3.396
15b2 Stbd Qtr	2.026	0.614	2.714
15b5 Following	2.056	1.409	2.721
DIW For Sea Kindliness			
Initial Head Sea	2.642	1.106	1.873

TABLE 19 - ROUGH WATER MOTIONS - ONE-TENTH HIGHEST AMPLITUDES

	WAVE HEIGHT	PITCH ANGLE	ROLL ANGLE
Foilborne In State 3 Sea: SAS Active			
17e1 Head Sea	3.665	0.583	0.997
17e4 Stbd Bow	4.132	0.606	1.081
17e3 Port Beam	3.895	1.115	2.725
17e2 Stbd Qtr	4.017	1.045	2.582
17e5 Following	4.328	1.146	1.667
Foilborne In State 3 Sea: SAS Secured			
17f1 Head Sea	3.219	0.579	1.728
17f4 Stbd Bow	4.426	0.909	1.956
17f3 Port Beam	3.867	1.235	2.570
17f2 Stbd Qtr	3.449	1.161	3.957
17f5 Following	4.186	1.577	3.275
Foilborne In State 5 Sea: SAS Active			
17a1 Head Sea	5.415	0.666	1.438
17a4 Stbd Bow	5.382	1.160	3.750
17a3 Port Beam	6.575	1.350	3.441
17a2 Stbd Qtr	5.517	1.400	2.913
17a5 Following	6.459	2.034	3.502
Foilborne In State 5 Sea: SAS Secured			
17b1 Head Sea	6.015	1.221	2.750
17b4 Stbd Bow	7.982	1.699	4.109
17b3 Port Beam	7.972	1.788	4.940
17b2 Stbd Qtr	6.000	2.336	3.943
17b5 Following	7.317	3.020	2.967
Hullborne In State 3 Sea: SAS Secured			
15b1 Head Sea	2.827	1.161	0.850
15b4 Stbd Bow	3.309	1.143	1.288
15b3 Port Beam	2.462	1.588	4.300
15b2 Stbd Qtr	2.570	0.824	3.200
15b5 Following	2.607	1.930	3.661
DIW For Sea Kindliness			
Initial Head Sea	3.240	1.370	2.390

TABLE 20 - RTA DERIVED ROUGH WATER ACCELERATION AMPLITUDES

STANDARD DEVIATIONS

	AT LCG		FWD CABIN	BRIDGE		AFT CABIN
	LATERAL	VERTICAL	VERTICAL	LATERAL	VERTICAL	LATERAL
Foilborne In State 5 Sea:						
SAS Active						
17a1 Head Sea	0.0592	0.1116	0.2200	0.1140	0.1720	0.1312
17a2 Stbd Qtr	0.0524	0.0792	0.1808	0.0828	0.1376	0.1200
17a3 Port Bea	0.0456	0.0796	0.1864	0.0920	0.1524	0.1180
17a4 Stbd Bowm	0.0504	0.0716	0.1968	0.0912	0.1368	0.1104
17a5 Following	0.0512	0.0616	0.1680	0.0860	0.1296	0.1208
Foilborne In State 5 Sea:						
SAS Secured						
17b1 Head Sea	0.0504	0.0812	0.1832	0.0856	0.1464	0.1124
17b2 Stbd Qtr	0.0388	0.0560	0.1564	0.0756	0.1296	0.1248
17b3 Port Beam	0.0580	0.0972	0.2208	0.1060	0.1976	0.1280
17b4 Stbd Bow	0.0408	0.0976	0.1888	0.0928	0.1820	0.1224
17b5 Following	0.0356	0.0608	0.1496	0.0740	0.1492	0.1204

TABLE 21 - PSD DERIVED ROUGH WATER MOTIONS AMPLITUDES
STANDARD DEVIATION VALUES

	WAVE HEIGHT	PITCH ANGLE	ROLL ANGLE	YAW* RATE
Foilborne In State 3 Sea: SAS Active				
17e1 Head Sea	2.094	0.240	0.467	0.560
17e4 Stbd Bow	2.046	0.257	0.520	0.553
17e3 Port Beam	2.120	0.526	1.286	0.779
17e2 Stbd Qtr	2.339	0.522	1.391	0.916
17e5 Following	2.212	0.494	0.765	0.753
Foilborne In State 3 Sea: SAS Secured				
17f1 Head Sea	1.939	0.260	0.792	0.458
17f4 Stbd Bow	2.033	0.322	1.145	0.565
17f3 Port Beam	2.097	0.612	2.212	0.806
17f2 Stbd Qtr	1.831	0.504	1.973	0.625
17f5 Following	2.308	0.713	1.444	0.650
Foilborne In State 5 Sea: SAS Active				
17a1 Head Sea	3.167	0.594	1.993	1.161
17a4 Stbd Bow	2.994	0.495	1.914	1.185
17a3 Port Beam	3.440	0.599	1.854	0.973
17a2 Stbd Qtr	2.912	0.617	1.461	0.815
17a5 Following	3.602	1.046	1.687	1.020
Foilborne In State 5 Sea: SAS Secured				
17b1 Head Sea	3.359	0.497	1.663	0.803
17b4 Stbd Bow	4.461	0.780	2.044	0.880
17b3 Port Beam	3.915	1.078	4.593	1.078
17b2 Stbd Qtr	3.301	1.154	1.647	0.728
17b5 Following	5.371	1.605	2.674	0.930
Hullborne In State 3 Sea: SAS Secured				
15b1 Head Sea	1.812	0.429	0.418	0.471
15b4 Stbd Bow	2.121	0.485	0.598	0.468
15b3 Port Beam	1.578	0.813	2.245	0.589
15b2 Stbd Qtr	1.647	0.418	1.936	0.606
15b5 Following	1.671	1.197	1.869	0.677
DIW For Sea Kindliness				
Initial Head Sea	2.066	0.621	1.324	

TABLE 22 - PSD DERIVED ROUGH WATER MOTION AMPLITUDES
MEAN VALUES

	WAVE HEIGHT	PITCH ANGLE	ROLL ANGLE	YAW* RATE
Foilborne In State 3 Sea: SAS Active				
17e1 Head Sea	1.834	2.095	-1.385	0.807
17e4 Stbd Bow	1.532	2.173	-1.651	0.772
17e3 Port Beam	1.549	1.937	0.265	0.963
17e2 Stbd Qtr	1.465	2.138	-1.113	0.987
17e5 Following	1.770	2.150	-0.573	0.827
Foilborne In State 3 Sea: SAS Secured				
17f1 Head Sea	1.679	2.334	-2.120	0.609
17f4 Stbd Bow	1.489	2.228	-1.790	0.771
17f3 Port Beam	1.805	2.401	-0.158	0.717
17f2 Stbd Qtr	1.632	2.420	-2.765	0.785
17f5 Following	1.541	2.361	-1.055	0.731
Foilborne In State 5 Sea: SAS Active				
17a1 Head Sea	1.547	1.944	-1.121	0.767
17a4 Stbd Bow	1.666	1.985	-1.099	0.702
17a3 Port Beam	1.530	1.903	0.660	0.763
17a2 Stbd Qtr	1.603	2.309	-2.650	0.832
17a5 Following	1.549	2.386	-0.185	0.808
Foilborne In State 5 Sea: SAS Secured				
17b1 Head Sea	1.434	2.259	-0.986	0.711
17b4 Stbd Bow	1.460	2.205	-0.993	0.731
17b3 Port Beam	1.349	2.090	-0.753	0.796
17b2 Stbd Qtr	1.789	2.197	-1.773	0.728
17b5 Following	1.527	2.471	-1.332	0.766
Hullborne In State 3 Sea: SAS Secured				
15b1 Head Sea	0.967	1.740	-2.167	0.735
15b4 Stbd Bow	1.163	1.513	-2.256	0.766
15b3 Port Beam	1.104	1.708	-0.777	0.664
15b2 Stbd Qtr	1.010	1.859	-3.138	0.741
15b5 Following	1.245	2.471	-1.332	0.766
DTW For Sea Kindliness				
Initial Head Sea	1.057	0.949	-2.501	

TABLE 23 - PSD DERIVED ROUGH WATER FLAP DEFLECTIONS STANDARD DEVIATION AND MEAN VALUES

	FLAP DEFLECTIONS			
	PORT FWD	STBD FWD	PORT AFT	STBD AFT
Foilborne In State 3 Sea: SAS Active				
17e1 Head Sea	-4.851	1.030	-3.197	-1.827
17e4 Stbd Bow	-4.920	1.319	-3.348	-1.916
17e3 Port Beam	1.189	-3.989	-1.407	-3.741
17e2 Stbd Qtr	-2.267	-0.828	-2.470	-2.460
17e5 Following	-3.980	0.303	-2.973	-2.403
Foilborne In State 5 Sea: SAS Active				
17a1 Head Sea	-2.888	-0.822	-3.316	-3.121
17a2 Stbd Qtr	-3.465	-1.589	-2.806	-2.769
17a3 Port Beam	*	*	0.137	-3.253
17a4 Stbd Bow	*	*	-4.067	-0.765
17a5 Following	*	*	1.569	0.211
Foilborne In State 3 Sea: SAS Active				
17e1 Head Sea	3.299	2.026	1.710	2.052
17e4 Stbd Bow	2.670	3.028	2.254	1.813
17e3 Port Beam	5.035	4.597	2.393	1.947
17e2 Stbd Qtr	5.032	4.600	2.653	1.881
17e5 Following	4.278	3.504	2.266	2.226
Foilborne In State 5 Sea: SAS Active				
17a1 Head Sea	4.044	3.946	3.066	2.686
17a2 Stbd Qtr	5.707	5.474	4.041	3.322
17a3 Port Beam	*	*	3.646	4.954
17a4 Stbd Bow	*	*	4.146	3.202
17a5 Following	*	*	5.162	4.686

*Flaps were fully deflected over intervals whose duration precluded analysis

TABLE 24. PSD DERIVED HULLBORNE ROUGH WATER ACCELERATION AMPLITUDES

STANDARD DEVIATION AND MEAN VALUES

	AT LCG			FWD CABIN		BRIDGE		AFT CABIN	
	SURGE	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL
Hullborne In State Sea 3									
15b1 Head Sea	0.0265	0.0239	0.0523	0.0437	0.0925	0.0622	0.1119	0.1095	0.0433
15b2 Stbd Qtr	0.0380	0.0502	0.0498	0.0555	0.0678	0.0728	0.1124	0.1169	0.0357
15b3 Port Beam	0.0397	0.0665	0.0609	0.0681	0.0756	0.0844	0.0984	0.1260	0.0454
15b4 Stbd Bow	0.0396	0.0363	0.0583	0.0526	0.1063	0.0684	0.1248	0.1191	0.0468
15b5 Following	0.0283	0.0388	0.0520	0.0556	0.0613	0.0703	0.1033	0.1168	0.0232
DIW For Sea Kindliness	0.0411	0.0591	0.0571	0.0566	0.0625	0.0656	0.0792	0.1144	0.0512
Mean Values									
Hullborne In State 3 Sea									
15b1 Head Sea	0.0634	0.0116	0.0016	-0.0290	-0.0057	-0.1171	-0.0152	-0.0735	-0.3464
15b2 Stbd Qtr	0.0645	0.0151	0.0068	-0.0246	-0.0036	-0.1226	-0.0221	-0.0699	-0.0474
15b3 Port Beam	0.0642	0.0057	-0.0008	-0.0423	-0.0031	-0.0987	-0.0258	-0.0944	-0.0481
15b4 Stbd Bow	0.0655	0.0290	0.0040	-[illegible]106	-0.0044	-0.1373	-0.0191	-0.0549	-0.0459
15b5 Following	0.0669	0.0081	0.0091	-0[illegible]298	-0.0057	-0.1150	-0.0191	-0.0792	-0.0460
DIW For Sea Kindliness	0.0446	0.0206	0.0025	-0.0218	-0.0110	-0.1375	-0.0194	-0.0645	-0.0645

TABLE 25 - PSD DERIVED FOILBORNE ROUGH WATER ACCELERATION AMPLITUDES
STANDARD DEVIATION VALUES

	AT LCG			FWD CABIN		BRIDGE		AFT CABIN	
	SURGE	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL
Foilborne In State 3 Sea: SAS Active									
17e1 Head Sea	0.0276	0.0471	0.0788	0.0695	0.2101	0.0790	0.1541	0.1094	0.0849
17e2 Stbd Qtr	0.0399	0.0735	0.0705	0.0904	0.2063	0.0963	0.1223	0.1135	0.0613
17e3 Port Beam	0.0224	0.0445	0.0446	0.0722	0.1871	0.0803	0.1159	0.1048	0.0472
17e4 Stbd Bow	0.0228	0.0339	0.0694	0.0649	0.2134	0.0735	0.1303	0.0965	0.0810
17e5 Following	0.0458	0.0625	0.0694	0.0806	0.2085	0.0945	0.1280	0.1085	0.0719
Foilborne In State 3 Sea: SAS Secured									
17f1 Head Sea	0.0332	0.0465	0.0834	0.0723	0.1976	0.0817	0.1551	0.0990	0.0827
17f2 Stbd Qtr	0.0207	0.0611	0.0533	0.0747	0.1957	0.0960	0.1222	0.1050	0.0557
17f3 Port Beam	0.0203	0.0648	0.0514	0.0809	0.1966	0.1006	0.1282	0.1081	0.0554
17f4 Stbd Bow	0.0219	0.0450	0.0729	0.0686	0.2077	0.0828	0.1359	0.0952	0.0845
17f5 Following	0.0416	0.0816	0.0650	0.0853	0.2082	0.1040	0.1344	0.1131	0.0785
Foilborne In State 5 Sea: SAS Active									
17a1 Head Sea	0.0808	0.0941	0.1308	0.1201	0.2267	0.1060	0.1827	0.1305	0.1313
17a2 Stbd Qtr	0.0753	0.1007	0.1127	0.1180	0.1954	0.1263	0.1496	0.1637	0.1150
17a3 Port Beam	0.0281	0.0616	0.0848	0.0895	0.1890	0.1157	0.1450	0.1154	0.0921
17a4 Stbd Bow	0.0244	0.0533	0.0819	0.0891	0.1983	0.0943	0.1412	0.1174	0.0938
17a5 Following	0.0549	0.0678	0.0819	0.0968	0.1831	0.0932	0.1341	0.1379	0.0776
Foilborne In State 5 Sea: SAS Secured									
17b1 Head Sea	0.0421	0.0619	0.1039	0.0955	0.2041	0.1069	0.1683	0.1303	0.1144
17b2 Stbd Qtr	0.0538	0.0688	0.0771	0.0[illegible]29	0.1726	0.0982	0.1344	0.1392	0.0745
17b3 Port Beam	0.0537	0.1104	0.1072	0.1294	0.1863	0.1494	0.1874	0.1665	0.0992
17b4 Stbd Bow	0.0305	0.0565	0.1115	0.0998	0.2174	0.1025	0.1999	0.1333	0.1232
17b5 Following	0.0637	0.0725	0.0752	0.0993	0.1626	0.1042	0.1587	0.1445	0.0543

TABLE 26 - PSD DERIVED FOILBORNE ROUGH WATER ACCELERATION AMPLITUDES
MEAN VALUES

	AT LCG			FWD CABIN		BRIDGE		AFT CABIN	
	SURGE	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL	LATERAL	VERTICAL
Foilborne In State 3 Sea: SAS Active									
17e1 Head Sea	0.0684	0.0032	-0.0003	-0.0422	-0.0034	-0.1160	-0.0270	-0.0827	-0.0545
17e2 Stbd Qtr	0.0670	0.0089	0.0067	-0.0356	0.0006	-0.1223	-0.0257	-0.0782	-0.0551
17e3 Port Beam	0.0624	-0.0181	0.0028	-0.0647	-0.0039	-0.0956	-0.0250	-0.1066	-0.0613
17e4 Stbd Bow	0.0648	0.0100	0.0048	0.0374	0.0058	-0.1227	-0.0288	-0.0761	-0.0544
17e5 Following	0.0641	-0.0016	-0.0006	-0.0483	-0.0054	-0.1100	-0.0236	-0.0882	-0.0564
Foilborne In State 3 Sea: SAS Secured									
17f1 Head Sea	0.0662	0.0185	0.0037	-0.0277	-0.0086	-0.1386	-0.0229	-0.0693	-0.0538
17f2 Stbd Qtr	0.0683	0.0203	0.0106	-0.0294	0.0040	-0.1314	-0.0273	-0.0714	-0.0548
17f3 Port Beam	0.0697	-0.0087	0.0066	-0.0551	-0.0040	-0.1023	-0.0265	-0.0991	-0.0555
17f4 Stbd Bow	0.0680	0.0302	0.0072	-0.0144	-0.0042	-0.1484	-0.0241	-0.0599	-0.0538
17f5 Following	0.0709	0.0091	-0.0029	-0.0398	-0.0036	-0.1193	-0.0272	-0.0846	-0.0533
Foilborne In State 5 Sea: SAS Active									
17a1 Head Sea	0.0722	-0.0004	0.0062	-0.0396	-0.0067	-0.1054	-0.0192	-0.0937	-0.0555
17a2 Stbd Qtr	0.0710	0.0094	-0.0017	-0.0330	-0.0065	-0.1055	-0.0176	-0.0872	-0.0529
17a3 Port Beam	0.0693	-0.0210	0.0085	-0.0650	-0.0128	-0.0725	-0.0174	-0.1184	-0.0562
17a4 Stbd Bow	0.0791	0.0373	0.0051	-0.0071	-0.0113	-0.1332	-0.0190	-0.0619	-0.0530
17a5 Following	0.0764	-0.0003	0.0085	-0.0466	-0.0081	-0.0940	-0.0196	-0.0969	-0.0551
Foilborne In State 5 Sea: SAS Secured									
17b1 Head Sea	0.0721	-0.0062	0.0051	-0.0939	-0.0078	-0.0979	-0.0184	-0.0893	-0.0483
17b2 Stbd Qtr	0.0731	0.0009	0.0054	-0.0368	-0.0048	-0.1083	-0.0180	-0.0848	-0.0500
17b3 Port Beam	0.0639	-0.0259	-0.0021	-0.0701	-0.0110	-0.0764	-0.0243	-0.1231	-0.0562
17b4 Stbd Bow	0.0738	0.0020	0.0022	-0.0375	-0.0064	-0.1121	-0.0184	-0.0785	-0.0488
17b5 Following	0.0712	0.0011	0.0031	-0.0273	-0.0109	-0.1173	-0.0204	-0.0728	-0.0501

ADDITIONAL ENGINEERING FACTORS

In addition to the operational characteristics and performance parameters evaluated in the Performance Evaluation Section, data were collected on hotel load, watertight integrity and moment to heel or trim. Several hydrostatic characteristics of the M-600 version of this ship are shown in Figures 71 through 74. Table 27 supports these figures.

Hotel Load

The hotel load of the RHS 200 was evaluated to be:

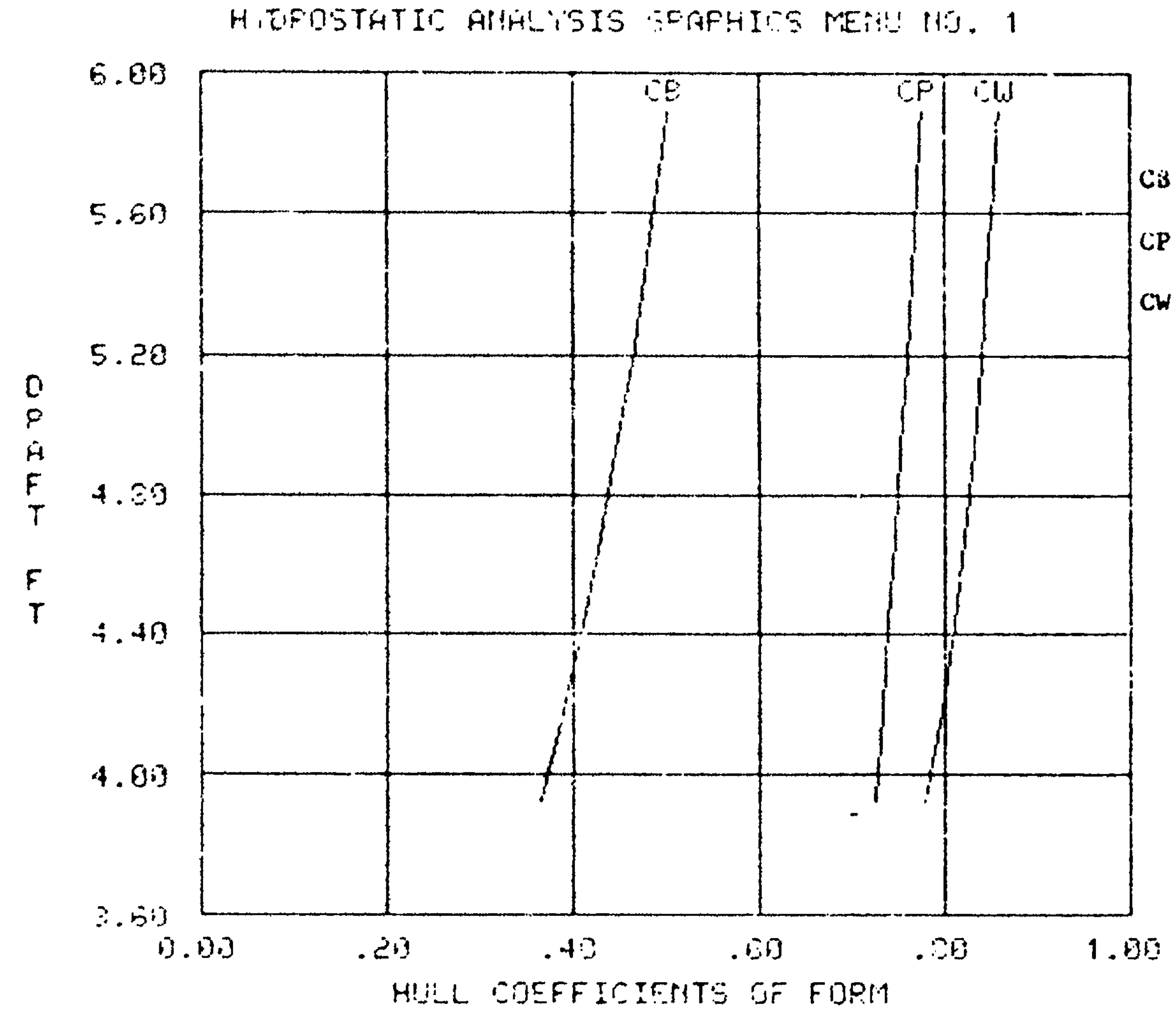
1. Electric
   - a. Normal 50kVA
   - b. Air Conditioning 50kVA
   - c. Total 100kVA
2. Hydraulic (Max) 17kW

The load requirements for the military version, M-600, have not been established. It is expected however, that the hydraulic load will not undergo a significant change. The normal electric load would most likely be higher due to more electronics such as a fire control system and sophisticated navigation equipment. This increased heat output would require a greater air conditioning load but the reduced requirement for passenger comfort might offset this increase.

Watertight Integrity

The vessel tested is only a prototype of the proposed RHS 200 and the counterpart military craft, the M-600. The structure is not the same as that intended in production vessels. In particular, the subdivision below the second deck has been revised. Floodable length calculations were performed based upon the proposed production RHS 200 design. Independent calculation confirms the accuracy of the floodable length information supplied by the builder. Examination of the Floodable Length Curve, Figure 77, reveals that the two-compartment standard is not met in the 95% permeability case. If a lower permeability is

01/13 83 13.02.25.



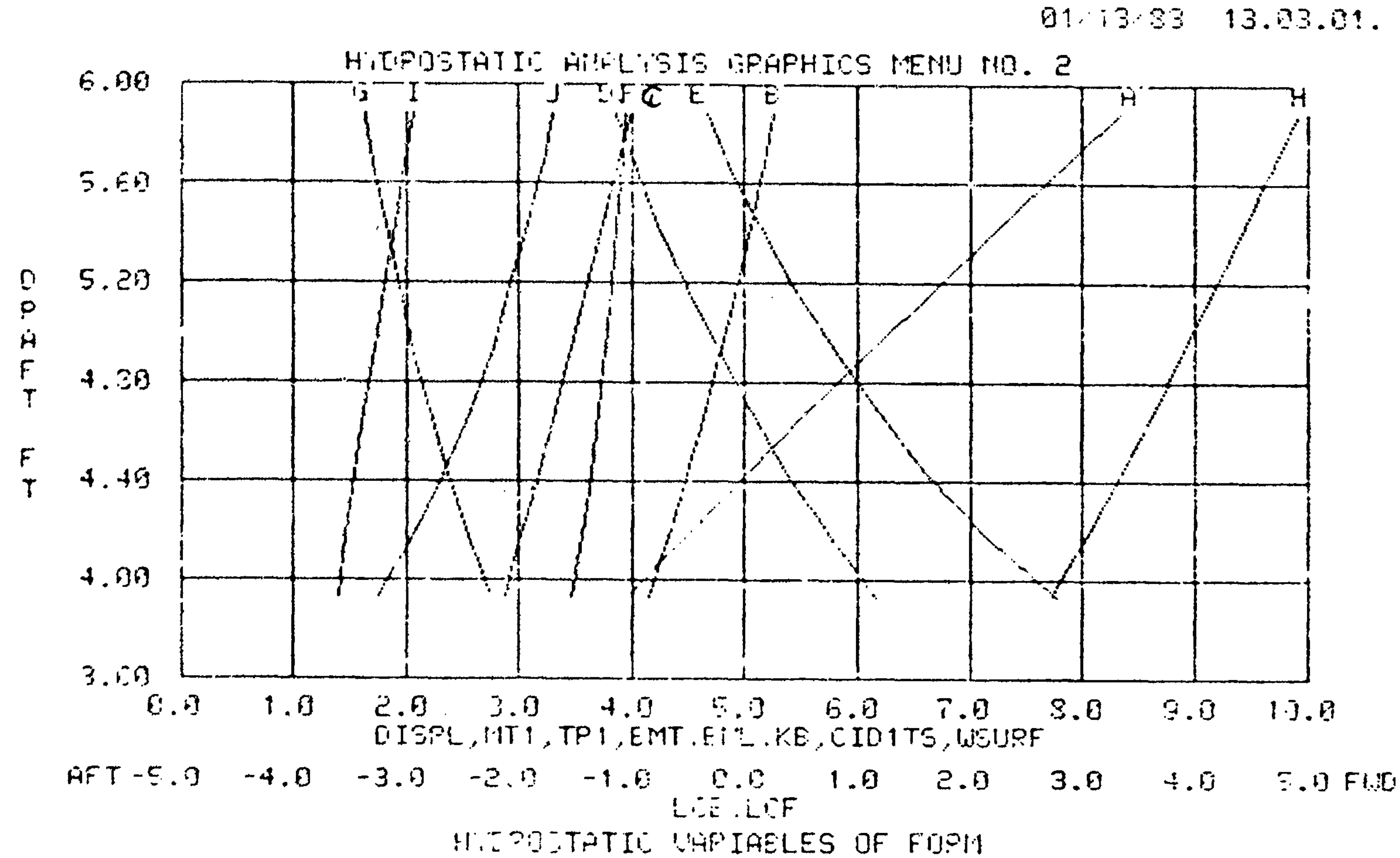
CB - Block Coefficient $\frac{\nabla}{L \times B \times T}$

CP - Prismatic Coefficient $\frac{\nabla}{L \times B \times T \times C}$

CW - Waterplane Coefficient $\frac{A}{L \times B}$

TRIM(+)E BY STERN, FT 1.41

Figure 71 - Hydrostatic Analysis: Draft vs. Hull Coefficient of Form



A Displacement (2Ø LTON/UNIT)
B Moment to Trim 1" (5 FT-LTON/IN/UNIT)
C Tons/inch Immersion (1 LTON/IN/UNIT)
D Transverse Inertia (2 FT/UNIT)
E Longitudinal Inertia (4Ø FT/UNIT)
F Height of Center of Buoyancy (1 FT/UNIT)
G Change in for one foot Trim by Stern (1 LTON/FT/UNIT)
H Wetted Surface (21Ø FT2/UNIT)
I Longitudinal Center of Buoyancy (2 FT/UNIT)
J Longitudinal Center of Floatation (Waterplane) (2 FT/UNIT)

TRIM (+VE BY STERN), FT 1.41

Figure 72 - Hydrostatic Analysis: Draft vs. Hydrostatic Variables of Form

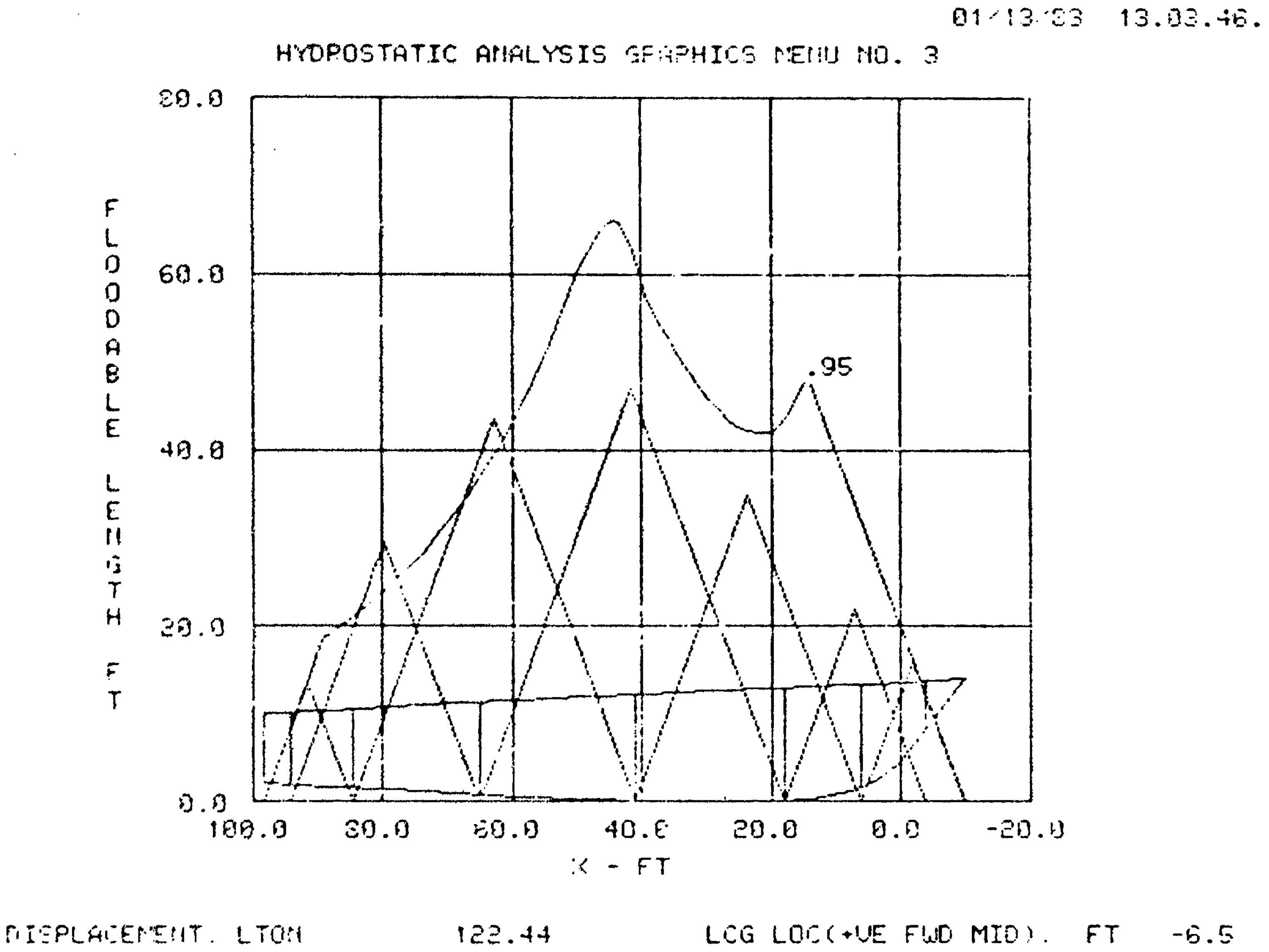
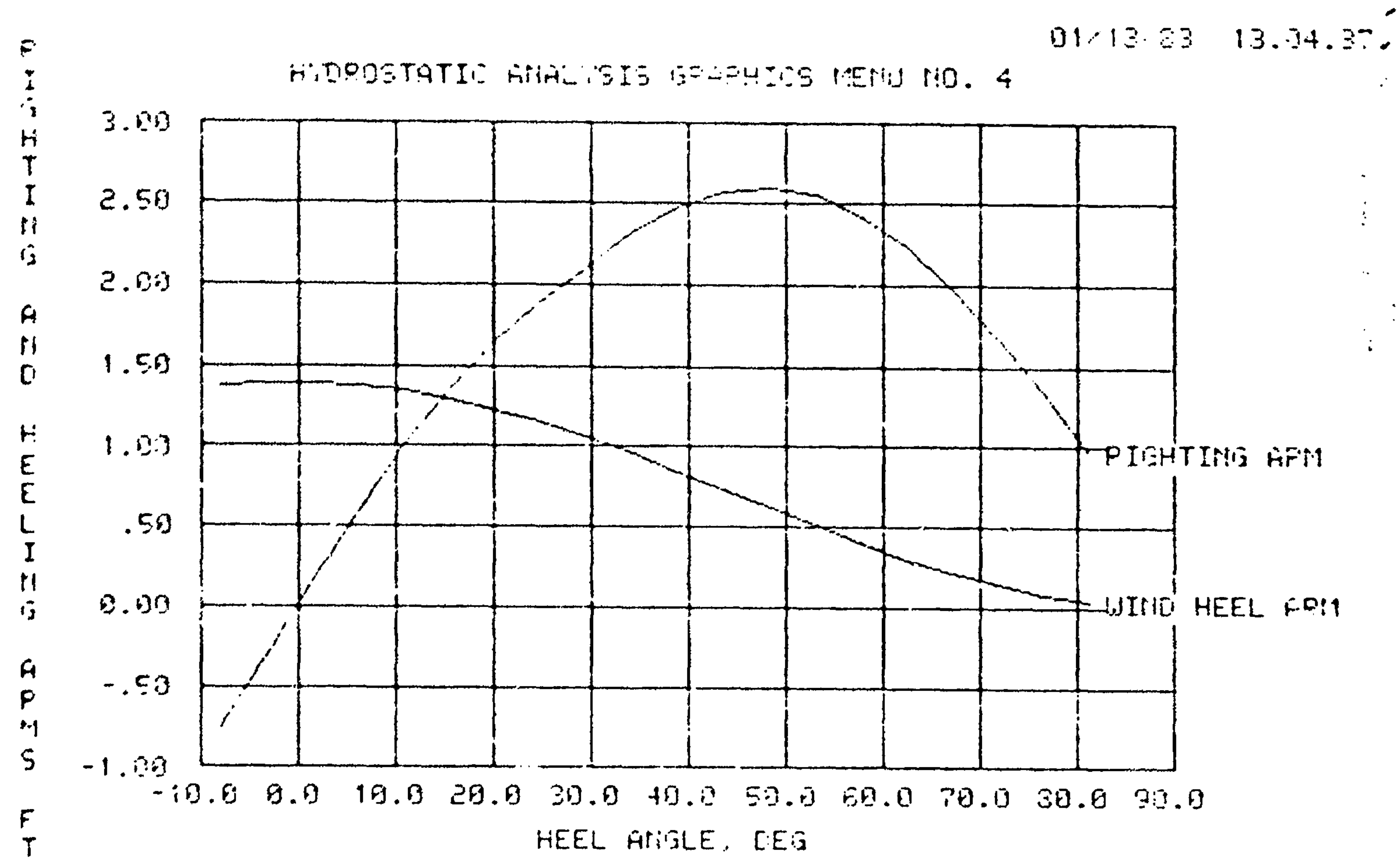


Figure 73 - Floodable Length



INTACT STATIC STABILITY

DISPLACEMENT, LTON	122.44	LCG LOC(+VE FWD MID), FT	-0.56
KG, FT	7.42	WIND SPEED, KT	100.00

Figure 74 - Intact Stability

Table 27. Hydrostatic Computer Program Input (N-600 Version)

```
CMD.ED HYDROSTATICS
 HYDROSTATICS
    HYDROSTATIC IND       = H WT LCG
    HYDROSTATIC DRAFT     =  6.23000     FT
    HYDROSTATIC WT        =  122.435     LTON
    HYDROSTATIC LCG       =  .566666
    HYDROSTATIC VCG       =  .634444
    CTP LAT PLANE BEL WL  =  3.12000     FT
    SAIL AREA FACTOR      =  .750000
    INTACT WIND SPEED     =  100.000
    TURN RADIUS           =  236.000     FT
    TURN SPEED            =  12.0000
    MARGIN LINE HT ARRAY  = FT
    ( 15 X  1)
 1  .1000E+37
    FL LGTH PERM ARRAY    =
    (  4 X  1)
 1  .9500
    COMP PERM ARRAY       =
    ( 11 X  1)
 1  .9500
 2  .9500
 3  .9500
 4  .9500
 5  .9500
 6  .9500
 7  .9500
 8  .9500
    COMP GROUP IND        = 1
    UNSYM COMP ARRAY      =
    ( 11 X  1)
 1  .1000E+37
CMD.ED
```

justified, the standard could be met. See "Acceptability Under USCG Requirements" in the Ferry Evaluation Section for a discussion of the adequacy of the ship's floodable length.

In the case of this particular vessel, each water tight bulkhead was examined from at least one side as a sample of the quality of construction. Bulkhead penetrations are kept to a minimum and are properly sealed. Bulkheads were constructed as shown on the drawings. No deficiencies such as skewed stiffeners were found. There were no apparent cracks or other faults found in the visual inspection. No hydrostatic tests were conducted.

Moment to Heel or Trim

At a displacement of 134 tons the following moments apply:

1. Moment to trim one inch = 24.75 ft.-tons
2. Moment to heel one inch = 4.37 ft.-tons

These values are independent of the Center of Gravity. The Vertical Center of Gravity of the RHS 200 SUPERJUMBO was determined by an inclining experiment on 14 January 1981 by the Registro Italiano Navale (RINA).

1. Displacement (light, 100 tons)
2. Vertical Center of Gravity (above baseline) - 6.1 feet
3. Longitudinal Center of Gravity (forward of AP) - 44.3 feet

OPERATIONAL PARAMETERS

Operations Equipment Arrangement

The comments below refer to the equipment layout on the RHS 200 and are in direct comparison with similar equipment on a WPB. Comments are included to signify known variations in the M-600 version:

1. The following equipment is easier or more convenient to use:
   a. Helmsman's chair can be adjusted to allow the helmsman to sit or stand without changing location. The chair provides support to the helmsman while is he standing.

b. Nagivation table

c. Ships intercom and PA system

d. Flag storage

2. The following equipment is more difficult or less convenient to use:

a. Helm and throttle controls are separated and require two men to operate.

b. VHF-FM radio communication equipment is difficult to reach.

c. Ship speed indicator. The ship speed is determined by a pressure transducer on a strut. The pressure level is transmitted to the bridge and converted to a speed readout on the speed indicator dial. This method is not very precise and is not used on U.S. hydrofoils. An electromagnetic speed log is preferred.

d. There is no anemometer installed on the RHS 200. The M-600 should be required to have this piece of equipment.

3. The following represents a positive factor in operational equipment arrangement. There are opening, tinted side windows and adjustable sun screens on the forward facing windows for the helmsman.

Visibility From the Deckhouse

The RHS 200 provides excellent visibility from the pilothouse. The only obstructions are at each stern quarter due to style/fashion plates. Figure 75 shows a representation of the visibility based upon an assumed eye level of 5 feet 6 inch above the deck. Visibility on the M-600 would be restricted aft and on the quarters.

Pierside, Offshore, Fog Navigation and Night Operations

An analysis of a vessel's operational capability is enhanced by the inclusion of these subject areas.

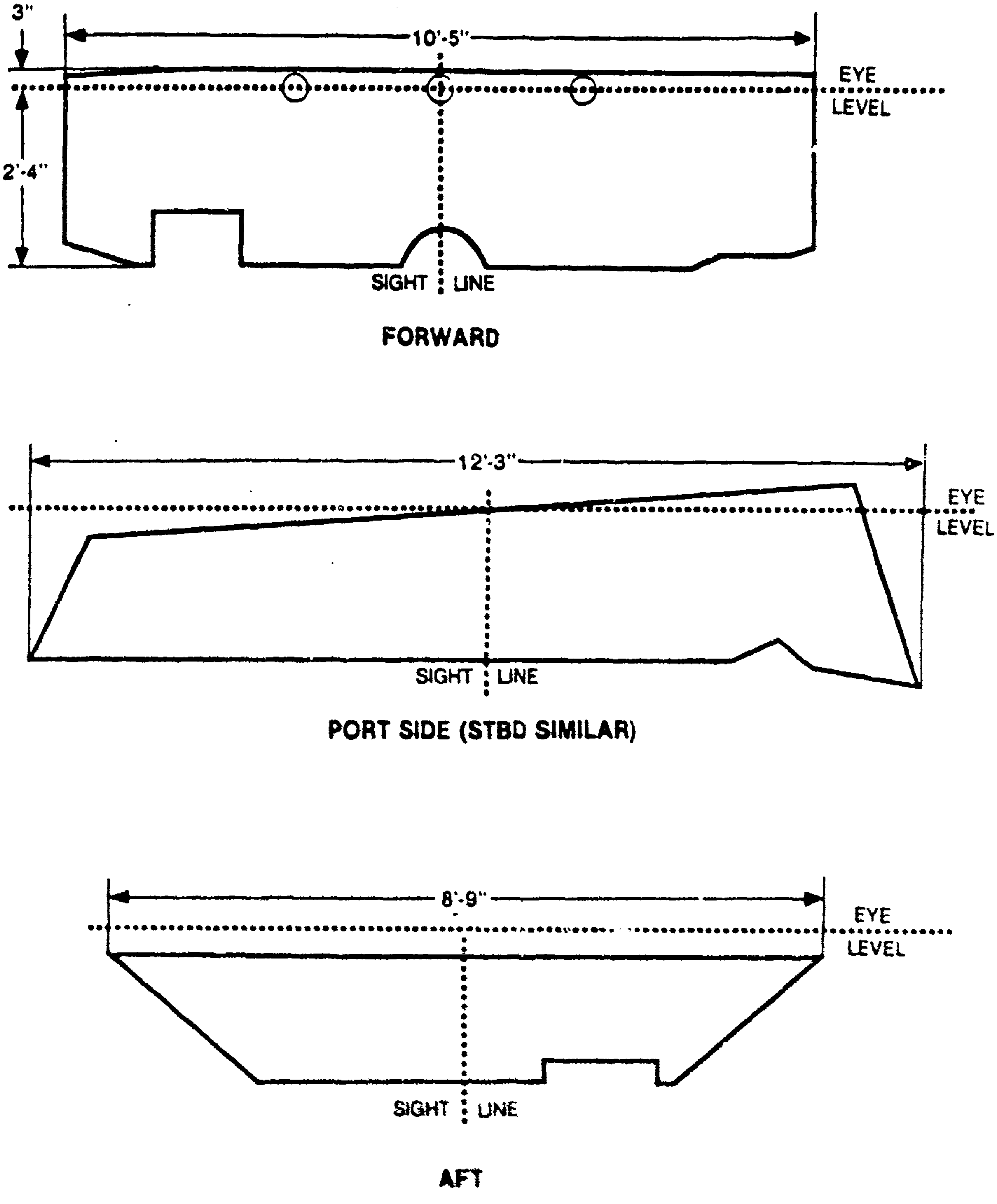


Figure 75. Pilot House Visibility From Captain's Chair

Pierside operation of the RHS 200 and M-600 version is somewhat more difficult than the WPB. The fixed, surface-piercing foil system dictates that the vessel be moored alongside adequate fenders or camel systems to ensure that the protruding struts/foils are not damaged by the pier. Consequently, boarding and loading operations are more difficult because of the increased distance from pier to ship. With reduced maneuverability at slow speeds, the RHS 200 docking procedures are more difficult. There were no difficulties foreseen with shore power connections.

Operation offshore will be discussed in greater detail in the sections on mission support capability; observed and subjective. Radar and navigation equipment were assessed to be easier to use than those of a WPB. Limited space and weight constraints reduce the capacity for underway replenishment gear. Vessel boarding and alongside operation are more difficult due to the extended foil system. The aft foil guards are suspended above the surface and a small craft could be damaged if caught underneath during a roll. The freeboard is a good height for boarding. Improved ship board motion at sea reduced crew fatigue.

The RHS 200 was not operated in fog or at night. However, high speed foilborne operation would be seriously limited in either of these cases. In some locations, special vision aids are required of commercial operators running high speed vessels at night.

DECK EQUIPMENT ARRANGEMENT AND OPERATION

The comments below relate primarily to the RHS 200. Differences associated with the M-600 are noted. Deck equipment consists primarily of generic items such as anchoring gear, capstans and bitts, the ships boat, etc. The M-600 may include other items inherent in a military mission.

Deck Equipment Arrangement

The deck equipment arrangement on the RHS 200 offered no particular difficulties in operation or maintenance. While the hull was considered much easier to maintain than the hull of a WPB and the deck equipment maintenance normal, it was judged that the deck and bitts were more difficult to maintain. None of the

equipment jeopardized the safety of operation. Anchoring equipment layout contributed to improved safety. Lack of hand rails posed a safety problem for some deck work but this problem can be rectified on future vessels.

Temperature ranges throughout the trials were moderate and did not contribute to any deck equipment failures. Extreme temperatures may offset some performance but only in a way that would be expected.

Motion, vibration and noise did not cause any difficulties to deck operations. However, high winds speeds over the deck while foilborne did make deck operations more difficult.

Anchoring

Anchoring was conducted in calm water. It was routine and very efficient; easier than on a WPB. There were no safety problems. There is no risk of damage to the ship, including the foils. The RHS 200 rides well at anchor. The chief reason for ease of operation is that the anchor rides in a bullnose at the bow ready for "letting go". The RHS 200 is frequently "Med Moored", requiring ease in anchoring. The capstan and anchor windlass were adequate.

Boat Launching Capability

The RHS 200 is not equipped with a true ship's boat. Life saving equipment consists of ten (10) twenty-five (25) passenger life rafts and one (1) fifteen (15) person life raft. During the time of the trials, these life rafts were being fitted with hydraulic releases. A small boat powered by a 2 HP engine was installed during the trials. No davit is provided and therefore boat launching and recovery were not observed. It is apparent that the necessary small boat equipment could be installed on the M-600 and that, due to the reduced motion, launching and recovery operations would be easier than on a WPB.

ENGINEERING EQUIPMENT ARRANGEMENT

The RHS 200 and the M-600 have unmanned engine rooms. Engineers enter the engine room only for starting and stopping the engines and for periodic inspection. Constant manning of the machinery is not required due to the excellent reliability of the propulsion plant.

The CP propellers could be converted to fixed pitch depending on the mission requirements. This would result in lower cost, less weight, and better efficiency at some speeds.

The machinery and their arrangement caused no problems with ship safety or maintenance. Engines and other machinery were easier to work on than on a WPB. Equipment outside the engine room was about as easy to maintain as on a WPB. Motions and vibration caused no special problems for the engineers. The engine room was noisier than on a WPB and good hearing protection is required.

Temperature caused no special problems. The MTU 16V652 engines have an exhaust temperature limit of 650 degrees C (1202 degrees F). This is quite high and was carefully monitored. It was sometimes necessary to reduce speed in a turn or seaway to maintain the exhaust temperature below this limit. The trials were conducted only in moderate ambient temperatures. Operations in extreme temperatures could result in difficulties. High temperatures for example, could result in reduced power and speed.

RELIABILITY AND MAINTAINABILITY

Reliability

As tested, the RHS 200 exhibited extremely high reliability. Not one corrective maintenance action was required during the trials period. The reliability of these hydrofoils is achieved by careful attention to design and selection of components and conduct of planned maintenance. The observation of a corrective action on a failure that had occurred before the trials period, the ease of trials equipment installation, and the conduct of planned maintenance indicate that this boat is easy to maintain.

Observed Operational Reliability, Maintainability and Availability

As indicated above, the operational availability of the RHS 200 was 100% during the trials period. Operational and maintenance cost data are presented in Table 28, as supplied by Rodriquez, for typical passenger operation. In

addition, Rodriquez has provided operational critiques from several companies employing Rodriquez hydrofoils in passenger service, Table 29. All of the reports indicate successful operations with Rodriquez hydrofoils.

TABLE 28. OPERATING AND MAINTENANCE COST ESTIMATE

FUEL USE *	299 gal/hr @ a speed of 35 knots 67 gal/hr @ a speed of 10 knots Useable fuel in tonnes - 5.16 (approx. $1.00/gal)	
OIL USE	5 kg/hr	(Approx. $1.00/qt)
MAINTENANCE	$75-$125 per Hour of Operation (low estimate)	
CREW COST	Subject to great variations from area to area Italian crew requirements and cost	
	1 Master	$ 30K/year
	1 Chief Engineer	30K/year
	1 Engineer	25K/year
	3 Deck Hands	20K/year each
	1 Deck Boy	15K/year
	3 Attendants	15K/year each
		$205K/year

* Induces both propulsion and auxiliary systems.

TABLE 29. HIGHLIGHTS OF PASSENGER SERVICE RELIABILITY MAINTAINABILITY AND AVAILABILITY PER RESPONDING COMPANY

1. Red Funnel Group; Southampton, England
   - RHS 70 Hydrofoil
   - 1,290,262 passengers since 1974
   - 51,617 trips totaling 557,500 miles
   - 1,026 trips list in six years. Two-thirds due to heavy weather, one-third due to mechanical difficulties.
2. Condar, Ltd; Guernsey, England
   - PT 50, RHS 140, RHS 160 Hydrofoil
   - 142,000 miles in 1979
   - 18 days lost to weather (2.2%); 2 days lost to mechanical failures (.24%)
3. A/S Dampskebsselskabetresund; Scandinavia
   - 5 Rodriquez Hydrofoils
   - 700,000 passengers per year
   - 10 000 trips per year
   - 97-98% technical regularity; 99% weather regularity
   - 8000-9000 hours between major overhaul on engines
4. Hong Kong Macao Hydrofoil Company; Hong Kong
   - RHS 140 Hydrofoils
   - 17,000,000 passengers in 16.5 years of operation
   - 18,940 trips and 719,720 miles
   - 97-98% operational reliability
5. Han Ryeo Development Co., Ltd; Seoul, South Korea
   - Rodriques Hydrofoil
   - 9 years of service
   - 1,000,000 passengers and 70,999 miles
   - 13% downtime due to weather or breakdowns
6. Urban Transit Authority; New South Wales, Australia
   - 5 Rodriquez Hydrofoils
   - 18,900,000 passengers in 15 years of service
   - 15,600 round trips
   - 2% breakdown

ABILITY TO SUPPORT MISSIONS

Observed Mission Support Capability

An important aspect of the RHS 200 performance trials was to project how capable the military version, M-600, would be in supporting various military missions. These mission support factors are described below.

Water Washdown. A water washdown system could be installed aboard the ship to wash down the entire main deck and deckhouse. No special equipment securing would be necessary.

Firefighting. The RHS 200, being constructed of aluminum, is restricted in it ability to approach a fire. Although it could use a fire monitor, if installed, it cannot get as closed to a fire as a conventional steel ship. A standard fire fighting system could be installed.

Damage Stability. This ship is designed to conform to a one compartment damage stability standard. In addition, the second deck is the bulkhead deck for most of the ship's length, which limits the ship's reserve buoyancy. Therefore it is subject to reduced damage [illegible]ity compared to a conventional WPB.

Cargo Capacity. This ship is suited for large volume cargo but is weight limited, making it less suitable for heavy ca[illegible]s. Cargo loading is complicated by the distance that the ship must stand off from the pier due to the protruding foils. With proper facilities, this problem can be easily overcome.

Oceanographic and Similar Work. The RHS 200 could be used to conduct oceanographic work provided that the weight of the handling gear is not excessive and that the ship structure is suitable. With the exception of the hazard posed by the foils, the handling of equipment over the side is similar to that on a WPB.

Underway Replenishment. The limited space and weight allowance available for replenishment gear are the only limitations on underway replenishment capability.

Helicopter Operations. Although the M-600 is advertised with a flight deck for very small helicopters, it is too small to operate helicopters of a practical size for the U.S. Coast Guard. The U.S. Navy has performed studies in which a helicopter flight deck for a LAMPS III (SH-60B) was included on a 196 foot long hydrofoil. A flight deck suited to USCG helicopters could probably be included

on a 164 foot hydrofoil, depending upon other installed equipment. There are no unique hazards to either on-deck or in-flight refueling of helicopters on the RHS 200. The U.S. Navy has demonstrated in-flight refueling on its hydrofoils.

Swimmer Support. There are no special hazards to putting swimmers in the water associated with the RHS 200.

Shore Tie Connections. Conventional shore tie connections can be used.

Sonar. A small, hull-mounted sonar could be installed on the M-600. However, the hull form would restrict it to a location very near the fixed, forward foils or further aft. In either case, flow noise from the foils over the sensor would tend to reduce the effectiveness of the sonar. A towed sonar could be installed. However, the weight and space restrictions associated with small vessels would apply. Current towed sensors would be limited to hullborne speeds.

Special Sensors. The RHS 200 and M-600 do not require special sensors or related equipments.

Submersible Support. An underwater communication system could be installed on the M-600. A small, two-man submersible could be carried, launched into the water, and recovered. However, this would require that adequate space be made available for the submersible and its handling gear, that their weight not be too great or cause trim problems, and that the ship structure be designed for such loads.

Subjective Mission Support Capability

The subjective comments on mission support were provided by Lt. Peter Boyd, USCG, who has operational experience with WPB craft.

Navigation. The speed of the RHS 200 is such that a plot cannot be kept using existing equipment. A real-time plot, such as the Decca Loran-C plotter is necessary. The Navy has developed the High-Speed Collision Avoidance and Navigation Systems (HICANS) using elements of the USCG COMDAC. This is specifically suited to the needs of high-speed ships operating in congested waters.

Communications. Standard communications equipment can be used with this ship.

Vessel Boarding. Coming alongside another vessel and boarding it would be difficult due to the surface-piercing foils extending beyond the deck edge. The aft foil guards extend beyond the sides like wings. A small boat could be caught

under one of these and damaged in a roll. However, the craft freeboard is just about right for boarding alongside.

Underway Replenishment. As discussed above, this is not expected to be a problem.

Swimmer Support. As discussed above, swimmer support capabilities are acceptable.

Helicopter Support. This is discussed in detail above.

Mooring. The submerged foils extending beyond the main deck require more care in mooring and unmooring the ship.

Loading. No particular difficulties in loading were experienced. However, this is somewhat more difficult than on a WPB due to the greater space between pier and vessel.

Pollution Cleanup Support. Pollution equipment deployment was not observed. However, the M-600 could be an effective means of transporting pollution equipment to an oil-spill scene.

Submersible Support. This is discussed above.

General Utility. The RHS 200 is faster (36 knot max speed), and provides a ride better than that of a WPB. It also accelerates and decelerates rapidly. In addition to its good foilborne ride, its low speed ride improved due to the submerged foils. Its fuel consumption is relatively high (250 gal/hr. at 34 knots). It also has a very large turning diameter at foilborne speeds. The RHS 200 was not fitted with gunwales or rails, making retrieval of a swimmer or victim more difficult than on a WPB. However, the M-600 is designed with line rails, improving this situation.

Subjective Seakeeping

Trial procedures called for filling out a Subjective Seakeeping Characteristics questionnaires by the crew of the RHS 200. The only comments available for analysis are from one individual, a Coast Guard representative. Areas subjectively analyzed included:

All-Weather Capability. Rough weather operation was not observed. Based on calm water operations, it was concluded that the RHS 200 would perform as well as, if not better than, a WPB in various weather situations.

Susceptibility to Icing. This area was not observed.

Spray Problems. Deck wetting caused by spray did not present a problem. It was concluded that the visibility from this vessel was better than that from a WPB.

Motion Sickness Problems. Due to improved ride control in the RHS 200, motion sickness probability is decreased.

Deadhead Susceptibility. Due to the fixed surface-piercing foil system, the vessel's susceptibility to damage from deadheads is increased.

Survivability

When foilborne, the RHS 200 is less susceptible to damage by underwater explosion by the fact that the wetted hull area is greatly reduced. The foilborne speed of the vessel also contributes to this feature. Decreased maneuverability while foilborne, however would tend to increase the vessel's susceptability to damage incurred on the surface. Submerged appendages may contribute to increased susceptibility to underwater explosive damage.

The light weight construction lends itself to increased susceptibility over a WPB. Overall, the survivability of the RHS 200 is enhanced by having the option to be hullborne or foilborne depending on existing conditions.

Interoperability and Logistics

In general, the interoperability and logistics features of this vessel are similar to those of a WPB. Fuel is readily available and fueling operations are about the same as on a WPB. The protruding foils and draft impose special considerations for piers discussed earlier.

Joint operations with helicopters were not observed. However, compared to the WPE, the higher speed of the RHS 200 may contribute to better control of the helicopter while hovering over a vessel. Also, the relatively large size of the M-600 can contribute to improving the helicopter pilot's vision of the ship. The steadiness of the M-600 can contribute to easier in-flight refueling or lifting of a person or equipment from the ship's deck. Joint searches are also expected to be easier due to the ship's speed.

Although combined operations with other Coast Guard vessels were not observed, they are expected to be about the same as on a WPB. Refueling or replenishment alongside another vessel is expected to be somewhat more difficult than on a WPB because of the protruding foils. Underway replenishment is addressed above. Passing or receiving a tow line is expected to be similar to that on a WPB. High speed towing of the M-600 may be possible.

Special training is required in high speed handling and high speed navigation. Local coast familiarization is also very important.

Habitability

The commercial passenger ferry, RHS 200, was tested. The comments in this section illustrate how a WPB could perform based upon the RHS 200 experience and the M-600 drawings. Therefore, they are somewhat conjectural.

Overall Habitability. Although some elements of habitability are not outstanding, the relatively comfortable motions of the RHS 200/M-600 contribute to habitability better than that of a WPB.

Facilities. Based on a review of the M-600 drawings, the berthing, messing, and sanitary facilities seem fair; roughly comparable to those on a WPB.

Each of the officers have private staterooms. Chiefs are located in double staterooms with two-high bunks. Seamen are located in a common berthing/messing area in bunks two and three high. The common berthing/messing area seems undesirable. In addition, this area is located below the Breda 40 mm twin gun.

Sanitary facilities for the seamen are inadequate; with one shower, three lavatories, and two waterclosets for 16 seamen.

Noise Level. The RHS 200 was mildly noisy throughout. This would be true on the M-600. The noise level would probably not affect one's ability to work but would be likely to affect his ability to sleep.

Ventilation and Air Conditioning. The RHS 200 was very poorly ventilated with both diesel fumes and exhaust finding their way into passenger spaces. These conditions can increase discomfort and quicken seasickness. In addition, the combat system electronics would increase the load on an already inadequate air conditioning system. This item would require considerable attention before using this vessel in a military version.

Motion. The reduced roll and pitch when hullborne and the reduced motion when foilborne compared to a WPB, would probably contribute to a better ability to work and sleep.

Vibration. Although vibrations were not severe in the pilothouse, they were quite bad in some locations and were greater than on a WPB. They could be expected to result in reduced work efficiency and ability to sleep.

One consequence of severe vibration and ship motion was great difficulty in printing legibly in both the upper and lower salons. This condition was worse in the foilborne mode.

SECONDARY VARIABLES

The secondary variables listed below were not specifically analyzed.

- Insulation and other cold weather protection
- Equipment vulnerability and protection from the elements
- Safety hazards
- Equipment arrangements not shown on plans
- Fire protection/equipment installed
  - CO_2/Halon system
  - sprinklers
  - location of vital cables
  - location of watertight doors
  - location of switches and fire pump
- Ventilation system
  - heating
  - heated windows
- Navigation equipment installed
- Boom capacity
- Dewatering gear installed
- Installed generator capacity
- Installed evaporator capacity
- Auxiliary engines installed (fans, etc.)

PASSENGER AND BAGGAGE CAPACITY

Passengers are supplied with individual row seats similar to those found on commercial passenger aircraft. No differentiation in seating class is made. All seats are arranged with a 33.5 inch pitch. Seats are 27.6 inches long.

The number of seats between aisles varies significantly. Some seats are individual. Most seats are arranged so that the passenger is in a seat which is no further than three seats from the aisle (counting his seat). A set of seats in the aft, lower salon, are arranged so that passengers are four seats from the aisle. Some seats in each lower salon are arranged facing aft.

The seats tested on the SUPERJUMBO were special seats used for promotional purposes and long voyages. They were similar to those on aircraft with folding tables, reclining capability, and deluxe seat covers. The seats for production boats on short routes would be significantly simpler for a weight savings of 11.25 pounds per seat or 2610 pounds for the ship. These would not have the folding table. Their reclining capability would be restricted and their seat covers would be simpler.

The RHS 200 SUPERJUMBO capacity is as follows:

Passengers	
Upper Salon	108
Lower Forward Salon	66
Lower Aft Salon	58
	232
Baggage	803 ft.^{3}

Baggage is stowed in two areas aft in the upper salon. These areas are for the baggage of all passengers and are on either side of the after entryway.

Four heads are provided. Two are in the upper salon, port and starboard sides, and one located in each of the lower salons.

A bar is located in the lower forward salon. It has a sink, refrigerator, storage, and hotplate. Together with its access, it occupies a space of 476.4 ft.^{3} with a deck area of 65.6 ft.^{2}.

PASSENGER ACCESSIBILITY

The RHS 200 SUPERJUMBO has been reviewed with respect to ANSI A117.1-1980 "Specifications for Making Buildings and Facilities Accessible To and Usable by Physically Handicapped People" (Reference 13). The vessel is clearly not designed for people in wheelchairs and could be made so only with considerable redesign, associated expense and loss of capacity. No particular uncorrectable difficulties for visually handicapped or hearing impaired people are apparent. Specific problem areas are described below. Section numbers refer to sections in the reference standard.

Wheelchairs

Entry. The aft and side entry doors provide about 47 inches clear opening. This is sufficient for entry by a wheelchair (S4.2.1). However, each door is fitted with a 6 1/4 inch high coaming. Several people would be required to lift the wheels over the coaming. Special ramps could be provided but these would be greater than 5 feet long (ANSI section 4.8). In the case of the side doors, each ramp would extend nearly to the ship center line. Portable coamings would probably not receive the approval of the regulatory bodies and would, in any event, result in increased loading and unloading times. The coamings must be included due to the potential for shipping water into the cabin and down to the lower salons.

Interior Movement. The movement of people in wheelchairs within the RHS 200 is severely restricted. The lower salons are essentially not accessible because of the stairways to those areas.

Any wheelchair-user entering through the aft door can only pass to the railing aft of the aft stairway. The passage beyond this is only one-half as wide as necessary.

Passengers entering through the side entries are restricted to the area between the stairs to the lower salons. Stanchions are located approximately 1.8 feet off the centerline at frame 49. However, sufficient clearance is available to permit movement of wheelchairs around these obstacles. Access in this central location is from side to side.

The positioning of wheelchairs in these areas is severely restricted. Wheelchairs in these locations could restrict the movement of passengers through the ship, particularly in an emergency situation.

Location of one row of wheelchairs in the aisle associated with the aft entry would be in a space only 51 inches wide. 64 inches is required for comfortable flow, 60 inches for restricted flow, and 48 inches is the minimum allowable (see section A4.2 of the ANSI standard). In addition, access to rows on the side would be blocked. This makes this area unacceptable for wheelchairs, given emergency use of this exit.

Using similar criteria for acceptable passage, an estimated five (5) wheel chairs could be located in the central area of the upper salon. This is the maximum number of spaces which could be safely devoted to wheelchairs (ignoring the coaming difficulty mentioned above). Use of entry ramps mentioned above, if permanently installed, would eliminate two of these spaces. Additional wheelchair locations could be provided by removing other seats.

Securing of Wheelchairs. At present, no provision is made for securing wheelchairs and their passengers. Securing of wheelchair passengers is absolutely necessary because of the motions exhibited by this vessel in normal and emergency operations. The securing devices used for this purpose could be adapted from similar devices used on subway rail cars.

Use of Heads. Heads in the lower salons are not accessible because of the reasons described above. The single head located in the upper salon is not accessible (Section 4.22.1 of ANSI standard). Its door is only 18 1/8 inches wide. The space is only 47 inches by 29 3/4 inches large (see Section 4.22.3 of ANSI standard). The toilet and lavatory do not meet the standards of sections 4.16 and 4.19 of the ANSI standard. The ANSI standard cannot be met with given the existing arrangement of the ship.

Other Considerations

This ship is adaptable to other requirements of the ANSI standard. Handrails and other obstacles are of the correct size, height, and distance from the bulkhead (Sections 4.4, 4.5, 4.9.4 of ANSI standard).

The requirements for stair tread width (ANSI Section 4.9.2) are not met because these are only 8.5 inches wide. This could be accepted either through a restriction, waiver, or modification.

Adaptations would be required to comply with the alarm, tactile warning, and signals requirement of ANSI standard Sections 4.28, 4.29, and 4.30, respectively.

PASSENGER COMPARTMENT MOTION

The pitch and roll motions and the vertical, lateral, and surge accelerations of the RHS 200 were measured at various locations throughout the ship during rough water trials conducted in State 3 and State 5 seas. It was found that the foil systems, even with the SAS disengaged, were very effective in limiting the motions of the ship while either hullborne or foilborne in a seaway. The accelerations which occurred were considered to be more severe than the motions. Although it was possible to move about the ship even in the heavier sea condition, it would be suggested that passengers remain seated during operations in State 4 seas or higher. Seat restraints were not installed nor were they required in any of the seas experienced during the trials. Roll and pitch motions were reduced with the SAS active. The SAS did not have appreciable effect on the measured accelerations. Numerical dafinition of the most significant results from these trials are presented in the Rough Water Response Characteristics section of this report.

CRAFT AVAILABILITY

The RHS 200 was operated underway on 12 separate voyages during the trials period. Although this figure is small in relation to the high number of voyages to be expected in a ferry service application, the important feature in the trials operation is that the tests were never postponed or delayed because of any equipment failure or maintenance activity. All normal maintenance needs were accomplished during warm-up periods or upon completion of a day's trials. Two of the noted voyages were made over a single weekend for the purposes of rough water trials. The first day's effort was mounted without any advance warning with ...

2-hour period. The ship had been in stand-down status with the engines secured the previous day. The information which Rodriquez has provided regarding the use of the RHS 200 during the June through September 1982 operating period, presented in the subsequent section on Operations and Maintenance, cites a schedule achievement of 94.4 percent. It is noted that this high level of availability was established over an open ocean, Naples to Palermo, transit which required over 12 hours for round trip completion. The experience of the DTNSRDC trials team was in agreement with the Rodriquez information; from reliability and maintenance points-of-view, RHS 200 availability must be assigned a very high value.

ACCEPTABILITY UNDER USCG REQUIREMENTS

The acceptability of a vessel under United States laws is determined by the United States Coast Guard (USCG). If an owner wishes to register a vessel in the United States, he must apply to the USCG, who will make a determination of suitability and the necessary modifications.

The following discussion can only be taken as an indication of the likelihood of approval and of those things which must be modified to receive approval. It is not an actual determination; that only being possible, on a case basis, by the USCG.

The rules applied to shipping are found in Title 46 of the U.S. Code of Federal Requlations (CFR) (Reference 14). The examination of this case will be in reference to the CFR. One of two subchapters is applicable to this vessel: either Subchapter H, Passenger Vessels; or Subchapter T, Small Passenger Vessels. Those vessels with less than 100 gross tons are considered "small". In order to determine which rule applies, the gross tonnage (a measure of the enclosed volume) must be found.

The estimate of tonnage is based upon the following assumptions:

1. The entire upper salon would be exempted as a sheltered space for protection of passengers on short voyages [(46 CFR 69.03-63(a)].
2. The entire wheelhouse would be exempted [(46 CFR 69.03-63(i)].
3. Neither the forepeak nor afterpeak could be adapted for the carriage of ballast because they are used for other purposes.
4. Neither doublebottom is counted.

The estimated tonnage of the vessel is 149.0 gross tons. This would require that the ship be registered as a Passenger Vessel under Subchapter H. Furthermore, 46 CFR 175.05-1(b) states that any vessel under 100 gross tons carrying more than 150 passengers shall comply with certain requirements of Subchapters F, H, J, and P as determined by the Officer in Charge, Marine Inspection. For these reasons, the ship will be primarily considered under Subchapter H.

The following paragraphs are an estimate of the likelihood of the vessel satisfying the requirements and in some cases the steps which might be taken to meet them. Paragraph numbers refer to the corresponding paragraph in the Code of Federal Regulations, Subchapter H.

This evaluation assumes that the RHS 200 will only be used for domestic voyages in open waters; this includes the ocean as well as rivers, lakes, bays, and sounds.

General Provisions (CFR 70)

This section describes general provisions and definitions and applies because the RHS 200 carries more than 150 passengers. These provisions shall all be assumed to be met except for:

70.20 - General Marine Engineering Requirements which refers to Subchapter F.

70.25 - General Electrical Engineering Requirements which refers to Subchapter J.

which will be discussed later.

Inspection and Certification (CFR 71)

This section describes the activites to be performed during design, construction, and operation. They are not relevent to this study.

Construction and Arrangement (CFR 72)

Hull Structure (72.01). The SUPERJUMBO RHS 200 was built to the requirements of the Registro Italiano Navale (RINA). The RINA requirements cover the areas of concern to the U.S. Coast Guard and those of the American Bureau of Shipping.

(ABS). Most likely, the ship could be built to ABS standards, thus satisfying the structural standards requirements of 46 CFR.

The watertight subdivision requirements can be met. The above paragraph on watertight integrity describes the inspection of watertight bulkheads. Although no testing could be performed during the trials period, the standard could certainly be achieved.

General Fire Protection (72.03). General fire protection is discussed under part 72.05, "Structural Fire Protection".

Structural Fire Protection (72.05). The code requires structural fire protection. This will definitely be required by the Coast Guard. Specific items are discussed below.

Fire Control Bulkheads and Decks (72.05-10). The code requires that the hull, structural bulkheads, decks, and deckhouses be constructed of steel or other equivalent metal. This ship is constructed of aluminum alloy. Aluminum does not have fire protection qualities equivalent to steel: that is, the insulating material necessary to ensure that protection has not been provided. Therefore, the aluminum cannot be considered to be equivalent to steel.

The code also requires that vessels be subdivided into main vertical zones not exceeding 131 feet in length. This ship, only 117 feet long, is not subdivided into vertical zones.

The hull, bulkheads, and decks are not constructed in such a manner that would appear to permit them to meet any of the standard fire tests (A or B). The code had established requirements for fire resistance based upon the type of spaces separated by the bulkhead.

Ceilings, Linings, Trim, Etc. (72.05-15). The plastic materials used for interior finishings, the carpet materials and the passenger seat materials have been approved by Italian agencies. Some will be approved by RINA and others were approved by the Italian aviation agency. However, the nature of the testing required by those agencies is not known. As a minimum, these materials would require testing under U.S. regulations, and would most likely require substitution by approved materials.

Stairways, Ladders and Elevators (72.05-20). Stairways are required to be constructed of steel. Those of the RHS 200 are not. The stairs to the lower salons of the RHS 200 have the following parameters:

Angle- 47° aft and 45° forward

Depth- 10 inches

Width- 46.25 inches

Height- 7.5 inches

All of these meet the requirements of the Code except those for the stairway angle, which must be limited to 40°. The stairway to the wheelhouse and the associated door must be widened to 28 inches. Handrails are approximately the correct height, but are constructed of aluminum. The stairways between passenger areas are not enclosed; therefore, they are not protected from fire. The location of these main stairways adjacent to the main machinery present a fire safety hazard which is also of serious concern.

Doors, Other Than Watertight (72.05-25). Some modification to the doors will be required. Most particularly, wire inserted glass, a minimum of 1/4-inch thick, must be used for doors opening onto safety areas from accommodation areas.

Windows and Airports (72.05-30). Wire-inserted glass is required for windows on lifeboat embarkation areas.

Hatch Covers (72.05-30). Not applicable.

Insulation, Other Than Fire-Protection (72.05-40). U.S. Coast Guard approved materials must be used.

Paint (72.05-45). This requirement is probably satisfied and certainly can be complied with.

Ventilation (72.05-50). Because there is no fire subdivision, most of these requirements are not applicable. The duct to the main machinery space which passes through the passenger space will require an automatic fire damper.

Furniture and Furnishings (72.05-55). See comments under 72.05-15.

Motion Picture Projection (72.05-60). Not applicable.

Vessels Before May 26, 1965 (72.05-90). Not applicable.

Means of Escape (72.10). Escape from the lower salons is inadequate for the following reasons. The main stairways from the lower salons exit into another accommodation area, not to the weather. Ready and direct access to lifeboat embarkation areas is required. Two independent means of escape are required. The RHS 200 has vertical escape ladders with deck hatches, and escape windows, as secondary means of escape. Subpart 72.10-15 specifically prohibits use of vertical ladders as a secondary means of escape. Where it is demonstrated that a stairway is impractical, a vertical ladder may be used. No use of escape windows is considered. The means of escape, especially from the lower salon, must definitely be upgraded.

Ventilation (72.15). These requirements are satisfied.

Accommodations for Officers and Crew (72.20). This is adequate because the ship is not intended for overnight voyages.

Passenger Accommodation (72.25). Separate male/female toilet facilities are required but not provided.

Rails and Guards (72.40). This requirement is satisfied.

Watertight Subdivision (CFR 73)

The design of watertight subdivision is dependent on several particulars of the ship's design and operation that are yet to be determined. The judgments regarding this ship are only indications of its expected performance. As a ship design is developed, the calculations to verify adequate subdivision will be performed.

The calculations supplied by Rodriquez were not in a format compatible with the requirements of the code. To the extent that was cost-effective, their calculations were checked and compared with the code. All indications are that the RHS 200 as tested, may not satisfy the one compartment flooding criterion.

Margin Line (73.05-6). The requirements for shear are defined in Section 73-05.6. This ship has a discontinuous bulkhead deck as described below. The margin line was assumed to be 3 inches below the bulkhead deck for each compartment.

Rules for Subdivision (73.15). This vessel is required to comply with Subpart 73.15 because it is under 150 gross tons and is intended for ocean or coastwise service, not for international voyages. One compartment subdivision is required.

The RHS 200 is unusual because the bulkhead deck is discontinuous. The main deck is the bulkhead deck for the engine room while the second deck serves that purpose for the remainder of the ship. The code makes no provision for vessels of this type construction at this size. However, Subpart 73.10-25, for vessels over 150 gross tons, does make such provision. For the purpose of this study, it will be assumed that the provisions of Support 73.10-25 do apply. This assumption requires confirmation by the Coast Guard.

To satisfy the requirement for the stepped bulkhead deck, two criteria must be met. First, the sides of the vessel must extend to the deck corresponding to the upper margin line throughout the vessel's length, and all openings below this deck throughout the vessel's length must meet the requirements for side openings below the margin line. Second, the two compartments adjacent to the "step" in the bulkhead deck must be within the permissible length corresponding to their own margin lines, and their combined length must not exceed twice the permissible length based on the lower margin line.

The vessel sides do extend to the upper bulkhead deck throughout the ship's length. The requirements for openings are addressed in subpart 73.40.

A check on floodable length was made for compartment IIC from frames 58 to 70 and compartment III, the engine room compartment. This was done with a conservative permeability of 0.95. The estimates of floodable length over these combined compartments is 17.3 feet. The combined length of the compartments is 35.4 feet which is 0.79 feet greater than twice the floodable length. This calculation is somewhat imprecise so further detailed calculation would be required. Some adjustment of bulkhead location could be made to correct a small deficiency, if present.

Collision Bulkhead (73.20-1). This requirement for both provision and location is satisfied.

Machinery Space Bulkheads (73.20-5). This requirement is met.

After Peak Bulkheads (73.20-10). This requirement for vessels over 150 gross tons is met.

Shaft Tunnels (73.20-15). This requirement does not apply.

Double Bottoms (73.25). No doublebottom is required on this vessel.

Penetrations and Openings in Watertight Bulkheads (73.30). To the extent that is possible to check, this requirement is met.

Watertight Bulkhead Doors (73.35). This requirement does not apply. There are no such doors.

Openings in Vessel's Sides Below Bulkhead Decks (73.40). This subpart does not permit openings in the side on vessels below 150 gross tons. This would eliminate the windows in the lower salons on this ship.

If the vessel was over 150 gross tons, non-opening port lights could be installed. These would require dead covers. The escape windows would certainly not be permitted. The windows are required to be of a substantial type approved by the Commandant. The windows used on the RHS 200 are unlikely to receive such approval; standard round windows would be required.

Watertight Integrity Above the Margin Line (73.45). No provision is made to limit the spread the water above the bulkhead deck. Although it would interfere with arrangement of the lower salons, coamings around the manholes to the spaces below the bulkhead should be considered.

Stability (CFR 74)

Stability Test (74.05). A stability test would be required.

Stability Standards (74.10). The minimum required intact stability is:

Weather criteria: GM (metacentric light) = 2.75 feet (req'd); where GM is defined as the distance between ship center of gravity and its metacenter.

Passenger criteria: GM = 1.69 feet (req'd)

In the full load condition, with passengers standing on the main deck, the worst case GM is 5.87 feet. The requirement is met.

Damaged stability: One-compartment flooding is required with damage extending to one-fifth of the beam and from the baseline upward without limit. The basic damaged stability requirement is met because of the very large intact GM.

However, as mentioned above, the margin line may be submerged along part of the length, thus violating this part of the damaged stability criterion. No cross-flooding or permanent or liquid ballast is required. Damaged stability must be carefully examined.

Lifesaving Equipment (CFR 75)

General Provisions (75.05). The lifesaving equipment provided must be of USCG approved type and made of approved materials.

Lifeboats, Life Rafts, Lifefloats, and Buoyant Apparatus (75.10). Subpart 75.10-25 states that inflatable life rafts may be substituted for lifeboats but that a rescue boat must be provided. This rescue boat must be seaworthy, rigid, with built-in buoyancy, readily launched, and easily maneuvered. It must be capable of being used to recover an unconscious person who has fallen overboard.

Hydraulic releases are required on all life rafts. Those on the SUPER-JUMBO were being so fitted during the trials period.

The total capacity of the inflatable life rafts on each side of the ship must be equal to one-half of the number of persons on board. The RHS 200 is fitted with ten 25 person life rafts plus one 15 person life raft. This is adequate for the 232 passenger version and may be acceptable on the 254 passenger version.

Buoyant apparatus are required sufficient for 25% of the persons on board (76 persons). Alternatively, inflatable life raft capacity may be increased by that amount.

Storage and Marking of Lifeboats, Life Rafts, Lifefloats, and Buoyant Apparatus (75.15). The life raft storage on the bow is unacceptable. Life rafts are to be capable of being launched while loaded with a full complement. This is not feasible on the RHS 200.

Equipment for Lifeboats, Life Rafts, etc. (75.20). The inflatable life rafts and buoyant apparatus must be equipped as specified in this subpart of the Code.

Davits for Lifeboats (75.25). Not applicable.

Inflatable Life Raft Launching Devices (75.27). The RHS 200 is deficient in not permitting boarding of life rafts before launching. Launching devices must be added.

Lifeboat Winches (75.30). Not applicable.

Blocks and Falls for Lifeboats (75.33). Not applicable.

Installation of Lifeboats, Davits, and Winches (75.35). Not applicable.

Installation of Inflatable Life Raft Launching Devices (75.37). These equipments are not required on domestic voyages.

Life Preservers (75.40). USCG approved life preservers must be provided as follows:

One per person aboard

+ 10% of number of persons, for children

+ one for each person on watch in engine room, pilothouse, and bow lookout station.

Life preservers, including those for children, are to be distributed throughout the spaces. If they are stowed in boxes, lockers, or closets, the boxes, lockers, or closets must not be capable of being locked (unlike those on the SUPERJUMBO). Each life preserver must have an approved, attached light.

Exposure Suits (75.41). Not applicable unless operated on the Great Lakes. If operating on the Great Lakes during the winter season, exposure suits equal to the number of life preservers must be provided. The stowage rules are the same as those applied to life preservers.

Ring Life Buoys and Water Lights (75.43). Eight life buoys are required. Six of these must have lights. This is currently exceeded on the RHS 200.

Line-Throwing Appliances (75.45). An impulse-projected rocket type or shoulder gun type line-throwing appliance must be provided with the associated equipment listed in the code. This was not provided on the prototype.

Embarkation Aids (75.50). Provision shall be made for embarking persons into floating life rafts. This includes adequate illumination of the entire process of launch from the stowed position until the life raft is waterborne.

Portable Radio Apparatus (75.55). Not required on domestic voyages.

Emergency Position Indicating Radiobeacon (EPIRB) (75.60). This is required unless the ship has an approved VHF radiotelephone and it will not be more than 20 miles from a harbor of safe refuge.

Ship's Distress Signals (75.90). Twelve approved hand-held, rocket propelled, parachute, red-flare distress signals must be provided.

Fire Protection Equipment (CFR 76)

Fire Detecting and Extinguishing System, Where Required (76.05). A fire main system, fixed fire entinguishing system (CO_2 and sprinklers), and hand portable fire extinguishers are required.

Fire Main System, Details (76.10). Only one fire pump is required. Water shall be delivered from the two highest outlets, simultaneously, at 50 psi. The pump shall be fitted with a pressure gauge and relief valve.

The hydrant and hose size are to be standard 1 1/2 inch. The hydrant nozzle is to be 1/2 inch. Fifty foot hose lengths are to be used.

Hydrants are to be located so that any place accessible to passengers and crew, except the machinery space, can be reached by two streams (at least one from a single length of hose) from separate outlets with doors closed. Currently, the RHS 200 has one hydrant on the stern, and one each port and starboard near the passenger doors. An additional two hydrants must be located in the upper salon. At least one hydrant must be located in each lower salon.

The machinery space also requires two independent streams but both with single lengths of hose. This requires two hydrants in the machinery space. Each fire hose must have combination solid stream and water spray nozzles. Two fire hoses must have applicators. Each hose in the machinery space shall have an applicator.

All hoses must be lined and Underwriters Laboratory approved. National Standard hose coupling threats must be used. These requirements can be met.

Steam Smothering System (76.13). This system must not be used.

Carbon Dioxide Extinguishing Systems (76.15). Carbon dioxide systems are required for the machinery space, forward paint locker, and aft paint locker. CO_2 is not required for the tanks. The following parameters apply:

Space	Capacity	Pipe Size	Nom. Cyl. Outlet Area
Machinery	242 lb	[illegible]	0.5 in.
Fwd Paint Locker	42 lb.	1/2 in.	0.1 in.
Aft Paint Locker	31 lb.	1/2 in.	0.1 in.

The machinery space lines are approximately correct, however the system capacity is very small. The paint locker systems must be added.

A delayed discharge system is required. An alarm must sound for twenty seconds in any space before CO_2 is discharged into the space. Provision shall be made for automatically shutting down ventilation to the machinery space when CO_2 is being used. Detailed specifications on system control and operation are described in the code and must be followed.

Foam Extinguishing System (76.17). Not applicable.

Manual Sprinkling System (76.23). Not required.

Automatic Sprinkling System (76.25). Not required.

Fire Detection and Smoke Detection Systems (76.26, 76.30, 76.33). Not required.

Manual Alarm System (76.36). Not required.

Hand Portable and Semi-Portable Fire Extinguishers (76.50). Some changes in the portable fire extinguishers are necessary. The following is the requirement for this ship:

Location	Number	Type
Stairway to Wheelhouse	1	AII
Each Salon	1	AII
Galley	1	BII or CII
Baggage Area	1	AII
Paint and Lamp Locker (each)	1	BII
Machinery Room	5	BII

Specifications for these are given in the Code.

Fire Axes (76.60). Two fire axes are to be provided.

Vessel Control and Miscellaneous Equipments. The requirements of this section are satisfied.

Operations (CFR 78)

This section is not applicable to the study.

Nuclear Vessels (CFR 79)

Not applicable.

Disclosure of Safety Standards/Registry (CFR 80)

Not Applicable.

Marine Engineering - Subchapter F

Major redesign of marine engineering systems will be necessary. Some of the important areas are:

Pressure Vessels (54)

Diesel Fuel Piping, Tank Vents, Tank Sounding (56.50-60, 56.50-75, 56.50-85, 56.50-90)

Lubrication Oil System Piping (56.50-80)

Main Propulsion Machinery (58.05)

Internal Combustion Engine Installation (58.10)

Electrical Engineering - Subchapter J

Electrical systems drawings are not available. However, based upon the different standards for voltage and frequency, major changes can be expected. This is compounded by the much more stringent standards imposed by the U.S. as compared to those in Italy. As a practical matter, a complete electrical system redesign would probably be required.

OPERATIONAL FACTORS

Pilothouse Visibility

Visibility from the pilothouse is excellent. Windows are placed so that 360 degree visibility is available. Thin mullions separate window panes; a slight movement of one's head permits visibility around any of these. The only exception is in the stern quarter direction. Fashion plates extending from each side of the deckhouse aft reduce visibility in those directions. (See visibility drawing in Figure 75.) Good views of the forward foil tips for docking, however, require observers on the bridge wings.

Instrumentation and Control Layout

Instrumentation and controls are positioned well. The captain is on the center line when at the wheel. The engineer is to his right and an observer is to his left. The captain has a speed log, a compass and Stability Augmentation System (SAS) controls. The engineer has machinery and electrical system

controls. The observer as a radar and radio. Electronic navigation equipment is located on the overhead, aft. Refer to the photographs at the end of this section.

Instrument visibility was generally good. However, ability to read the digital exhaust temperature unit suffered in bright light. The engine and shaft speed indicators could not be easily viewed from any position other than the engineer's location.

Night Operations Capability

Although the craft is equipped with radar, a night version capability would most likely be required for its operation in congested waters. This is due to its much greater speed than other vessels likely to be present. The ship was not operated at night during the test period.

PIER FACILITIES SUPPORT

Minimum Water Depth

At full load weight, the RHS 200 draws 15.3 feet of water. To ensure adequate clearance, the water depth should be 3 feet greater at low tide (dependent upon local tidal ranges). This will accommodate the ship in a trimmed condition or at a very low tide.

Fenders and Camels

The overall width of the RHS 200 forward foil is 47.6 feet. The hull width is only 23 feet, leaving a 12.3 feet overhang on each side. Camels 14.8 feet wide should be used to prevent damage to the foils. Fenders should be used due to the minor potential for damage to the ship's aluminum hull.

Ramps

The RHS 200 terminal should include ramps to reach the entry/exit points. These must extend beyond the fenders to the deck. In general, these ramps would be similar to those used for conventional, small passenger ferries. Other mooring requirements are similar to those for a conventional ferry of the same size.

Shore Connection

Electrical. A 220V, 50 kW electrical panel must be provided for shore power.

Water. No special water facilities are needed. A small garden hose is needed for washing down the ship after operation.

Sewer. No sewer facilities are used on the ship in Italy. For American operations, a holding tank or other processing system would be required.

MANNING REQUIREMENTS

The manning requirements for a vessel vary greatly based upon location, regulations, union rules, maintenance program and type of service. Therefore only an example manning roster can be provided.

The RHS 200 SUPERJUMBO has operated on a run between Palermo and Naples. It required about six hours in each direction and makes one round trip daily. The ship's crew is as follows:

Category	Number
Captain	1
Chief Engineer	1
Mechanic	1
Sailors	2
Hostess	1
Barman	1

Other hydrofoils operate from each of these terminals. Therefore, the shoreside personnel are not devoted to this ship. Typically, a manager, two assistants, and two laborers are stationed at each terminal. The manager and assistants are responsible for selling and taking tickets and administration while the laborers assist in mooring the hydrofoils and perform terminal maintenance.

Planned maintenance and most corrective maintenance is performed by the ship's crew. Specialists are used for jobs requiring unusual skills. Extra personnel are used for large jobs. On the average, one mechanic per day is required. This ship must also be docked once per year. This depot level labor is not considered here.

When a vessel operated in the United States, the crew complement is subject to the judgement of the Officer in Charge, Marine Inspection (46 CFR 157) and the union. Because this is covered on a case basis, no determination of crew size for U.S. operations is made here.

Manning will also depend upon the labor contract agreed to by the operator and the union. These, in turn, depend upon the particular service. However, it is most likely that these manning levels will be greater than those required by the Coast Guard. In developing other hydrofoil passenger service in the United States it was found that for vessels over 100 gross tons, the operator would have to be forced to negotiate with 17 different maritime unions vice only one union for the smaller ship. The larger number of unions would, almost certaily, have resulted in a larger crew. An assessment of crew size must await a proposed deployment plan.

CRAFT OPERATING PARAMETERS

The calm water speed and powering operational parameters of the RHS 200 were evaluated under light and heavy ship test configuration. The results of these tests which considered normal hullborne and foilborne operation and limited single engine hullborne tests are presented in detail in the Calm Water Speed and Power section of this report. Similar data were obtained at single speeds hullborne and foilborne in State 3 seas and foilborne in State 5 seas. These results are presented and compared with calm water results at the same speeds in the Rough Water Ship Performance section of this report. These sections also include respectively, discussions of the wide scope of calm water, and the more limited rough water, takeoff tests that were performed. Ship performance was largely as advertised. A typical maximum foilborne speed of 36 knots was achieved at full power conditions. State 3 sea operation did not have noticeable effect on speed and power requirements. In State 5 seas typical power increases of 11 percent were required to achieve the same speed if the SAS were active. Required power increased to between 17 and 31 percent and speed was reduced with the SAS secured. The ship has a 50 percent calm water takeoff power margin. Rough water takeoff powering requirements, which included five ifferent headings is State 3 seas and only head sea cases in State 5, were not largely different from the calm water requirements.

EMERGENCY OPERATING PROCEDURES

Emergency operating procedures for the RHS 200 were not considered in the trials beyond the evaluation of both single engine hullborne speed and powering characteristics, and hullborne and foilborne emergency stopping characteristics. The ship, in the event of damage to or the failure of a single propulsion plant, could readily make an extended hullborne transit at speeds up to 12 knots. Details of the single engine tests and their results are included in the Ca Water Speed and Power section of this report. The stopping characteristics of he ship are summarized and the tests are cited in a following section. Emer y procedures relative to life boats, fire fighting and similar aspects are reviewed in the section titled "Acceptability Under USCG Requirements."

HOUSEKEEPING CHARACTERISTICS

The RHS 200 is generally well-suited to maintenance. The only difficulties are cleaning the carpet around the seats and the potential for stains on the carpet or seat covers. The floor is carpeted throughout the passenger areas which requires vacuuming. The seat covers are a synthetic material. The susceptibility of shipboard materials to fire has been discussed previously in the section "Acceptability Under USCG Requirements," part 72.05-15.

MANEUVERABILITY

RHS 200 maneuverability was evaluated in calm water spiral turning tests designed to explore rudder effectiveness and ship directional stability limits, in tactical diameter trials, in low speed maneuverability tests, in zig-zag maneuvers, and in special tests designed to demonstrate differential thrust turning capability at zero speed of advance. The specifics of all of the tests and discussion of their results are given in the Calm Water Turning section of the report. Hullborne turn rates to 3 degrees per second were achieved. Maximum foilborne rates were slightly less. Due to a combination of high speeds and low turn rates, foilborne tactical diameters were 555 yards at 28 knots and 920 yards at 35 knots. Hullborne minimum tactical diameters of 270 yards and 360 yards at speeds of 8 and 16 knots respectively, were determined. The rudders were found to still be effective at speeds below 2 knots. The ability to measure speed expired before rudder effectiveness. No directional instabilities were found.

Zero speed of advance turn rates of 2 degrees per second were demonstrated. The zig-zag tests showed that the ship responded very quickly and accurately to the helm. The limited rough water turning tests are discussed in the Rough Water Turning section. The rudders were effective at 2 degrees of deflection in head and following State 5 seas. Calm water turning capability was not reduced in State 3 seas. With the SAS active there was also little or no reduction in turn capability in State 5 seas. In these sea conditions the Captain of the RHS 200 elected to use reduced rudder command when turning with the SAS secured.

STOPPING CHARACTERISTICS

The crash stop and crash reverse characteristics of the RHS 200 are discussed in the Crash Stop Response section of the calm water performance evaluation. It was possible to stop the ship in 30 yards, or less than one ship length, from an initial hullborne speed of 16 knots. It was possible to stop the ship in 96 yards, or 2.50 ship lengths, from an initial foilborne speed of 35 knots under crash reverse conditions. The distances required to stop the ship under crash stop conditions were only slighter longer. The CP propellers were believed to be of added benefit in the emergency stops.

STRUT FAILURE CONDITION

The welded foil system assemblies of the RHS 200 are attached to primary hull structure at bolt-on attachment points. The attachment fasteners are designed to shear under foil impact loads. In such a scenario the damaged foil would fall away from the ship and a crash landing would occur. The low flying height of the RHS 200 and the shape of its hull would permit a gentle crash landing. The most severe factors to be expected would be the negative surge accelerations which would occur with the impact loads on the foil. The load levels at which the attachment bolts would fail were not defined.

WAKE EVALUATION

The bow generated wave train of the RHS 200 was recorded during ship transits past a near-shore instrumentation station. Typical height versus time

traces of the wave series are presented and discussed under the Wake Evaluation section of the performance evaluation. In either the hullborne or the foilborne mode of operation the RHS 200 bow wake was nearly 2.0 feet peak-to-peak and each wave had a period of approximately 2.5 seconds. The wave series typically contained 5 well-defined waves.

OPERATION AND MAINTENANCE

The following operation and maintenance information was obtained from Rodriquez Cantiere Navale based on the 1982 operating season; 30 May 1982 through 1 October 1982.

Personnel Complement and Skills

During the 1982 season the vessel operated with two crews made up as follows:

Master

Chief Engineer

Engineer

2 Seamen

3 Apprentice Seamen

No shoreside maintenance support was expected. Maintenance was carried out by the ship's personnel with the help, whenever necessary, of a local companies personnel or personnel from the Rodriquez shipyard.

List of Expendable Parts and Equipment

The aggregate cost of these items was approximately $6,170.00 (Based on 1300 Lira per U.S. Dollar). The items consisted of:

3 zinc anodes

4 ball and socket joints; Guso D

80 kilos of paint

1 wildcat

2 hydraulic cylinders

1 safety governor ring DR 6262

Operation Hours and Cost

1050 Hours at a cost of $712,962 US, broken down as follows:

Crew	$199,629
Fuel	$363,611
Lube Oil and Other Consumables	$14,259
Agency Changes and Harbor Dues	$28,519
Annual Maintenance (Inc. O/H and Storage)	$106,944

Maintenance Manhours and Cost (During Operations)

910.5 Manhours at a cost of $14,020 US

Load Factor

An average of 25.5%

Utilization of the RHS 200

80.8%

Fare Structure

Not available.

Planned Schedule and Frequency of Operation

From 1 May to 20 September; six days per week with one day held in standby.

Percentage of Time Schedule Met

94.39%

Scheduled Trips Missed and Why

3rd and 4th of June; Replacement of a bent propeller blade.

13th of June, 26th and 28th of July; Adverse sea conditions.

1st of September; Damage to fresh water pump.

Average Time to Load and Unload

150 passengers in 10 minutes

5000 kilograms of luggage in 15 minutes (simultaneously with the passengers)

Weather Experience

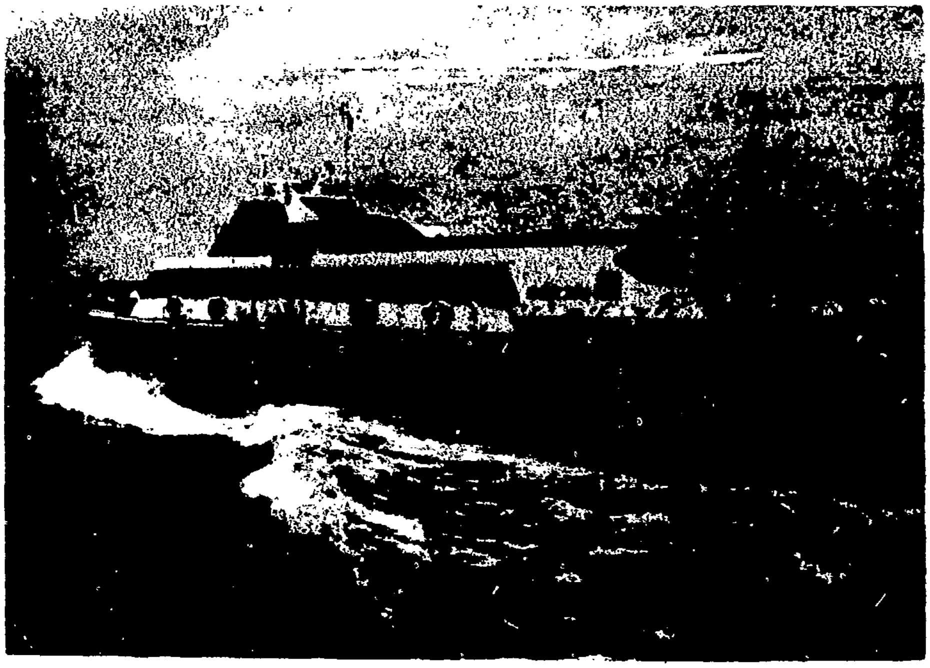
Meteorological conditions during the last operation period were generally good. In rough sea conditions, the most frequent situation was a WNW wind and sea with an accompanying State 3 or 4 sea (possible taken from the Beaufort Scale). State 7 seas were experienced on some days. When this occurred, the trips were cancelled. However, when the sea state increased to 7 during a trip already started, it was necessary to reduce the speed to about 29 knots in head and quartering seas. A few times, say less than five per trip, the vessel came off foils to avoid unnecessary damage risks by anomalous waves. In both sea directions, the take-off was easily accomplished after an occasional landing by placing the ship in a beam sea.

Equipment Casualties and Emergencies

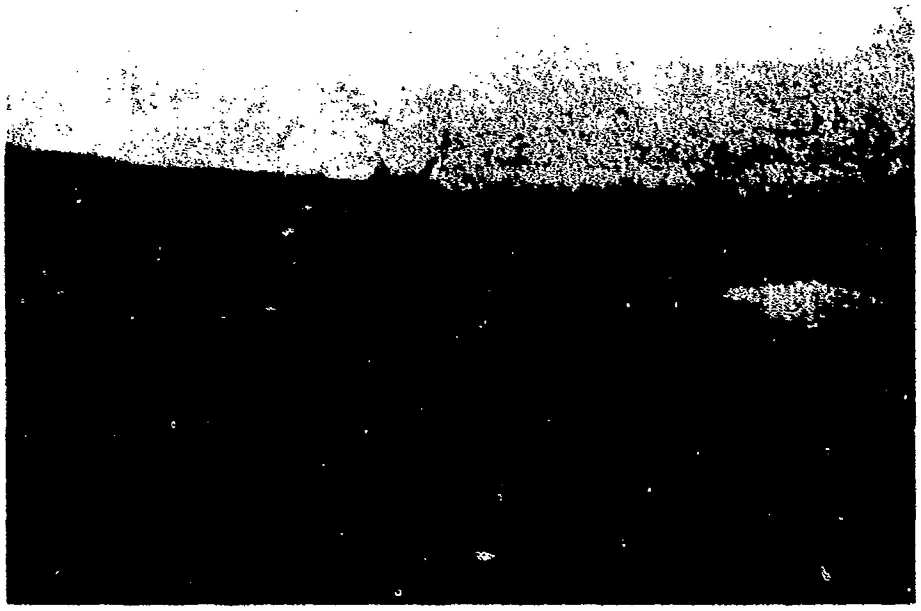
There were no important casualties or emergencies experienced that would have been the cause of any damage.

Photographs

Photographs on the following pages show a series of selected external and internal views of the RHS 200 hydrofoil.

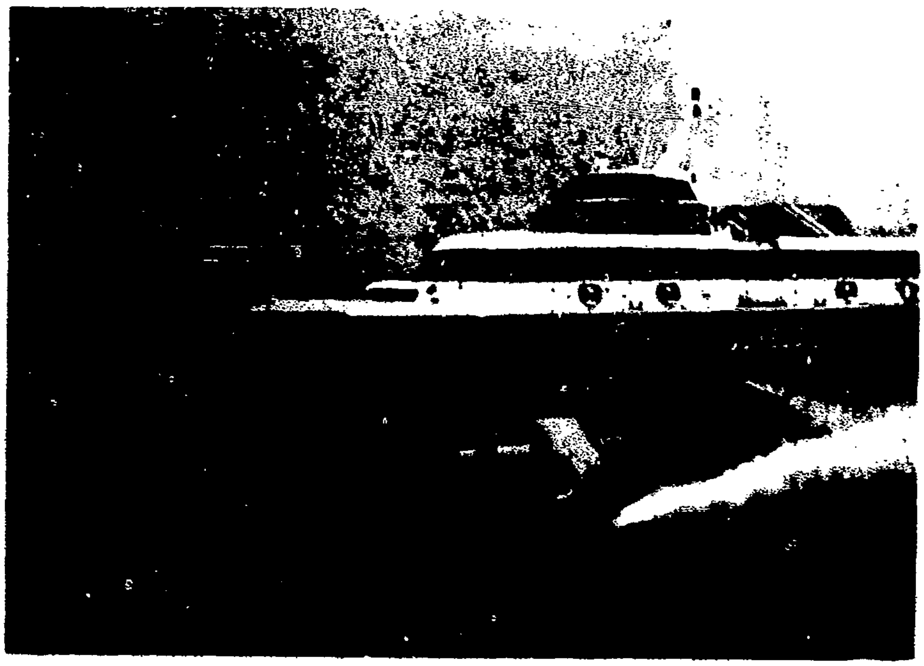


RHS 200 During Landing



RHS 200 During Takeoff

RHS 200 Foilborne

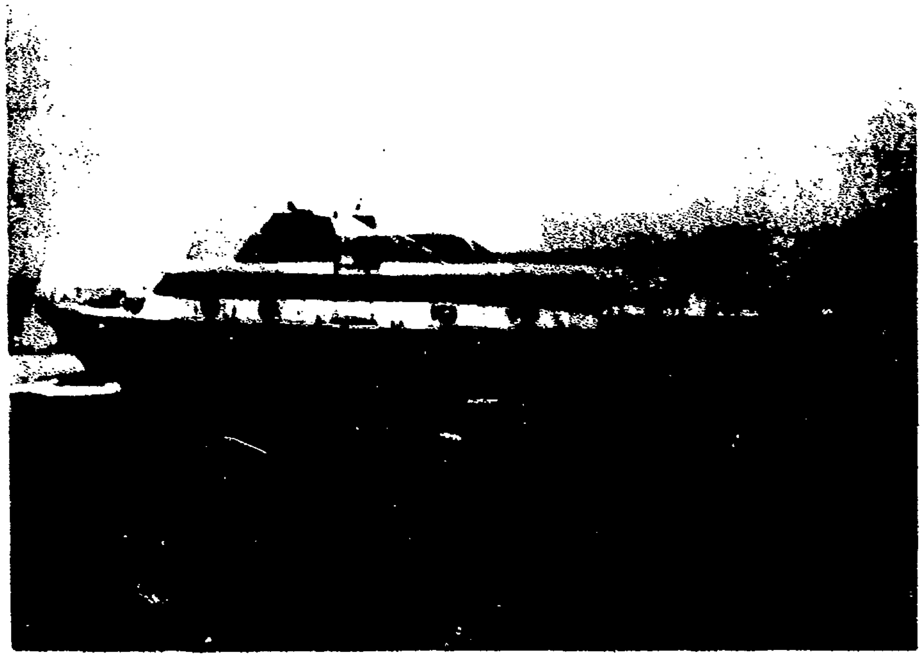


RHS 200 Foilborne

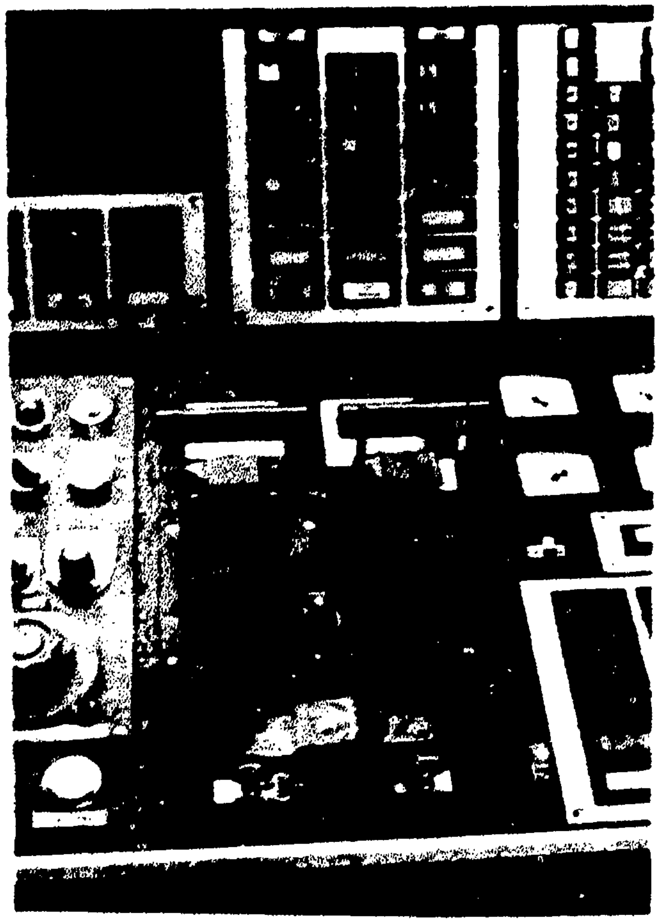
RHS 200 Foilborne

RHS 200 Foilborne

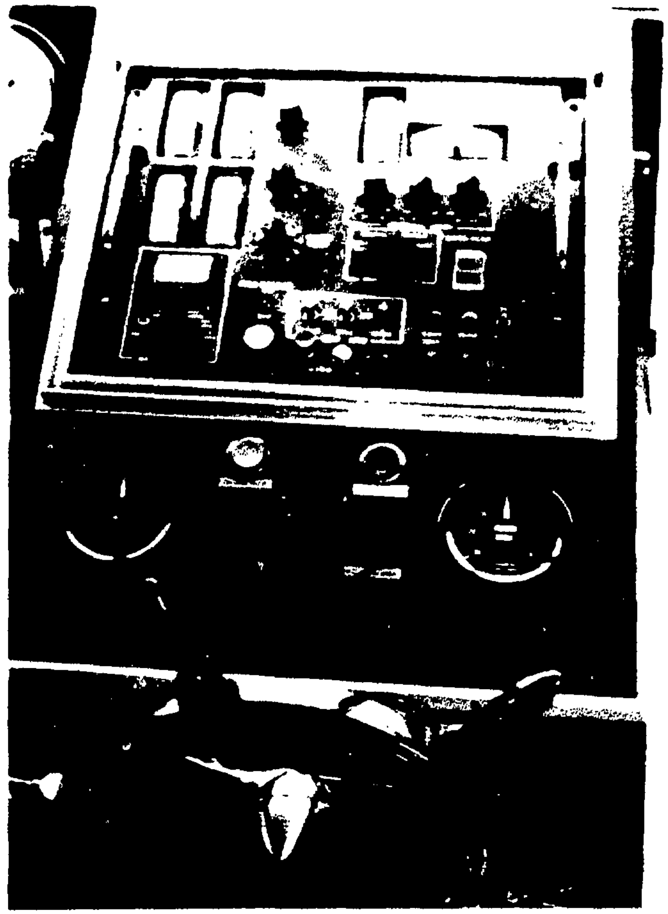
RHS 200 Hullborne - DIW



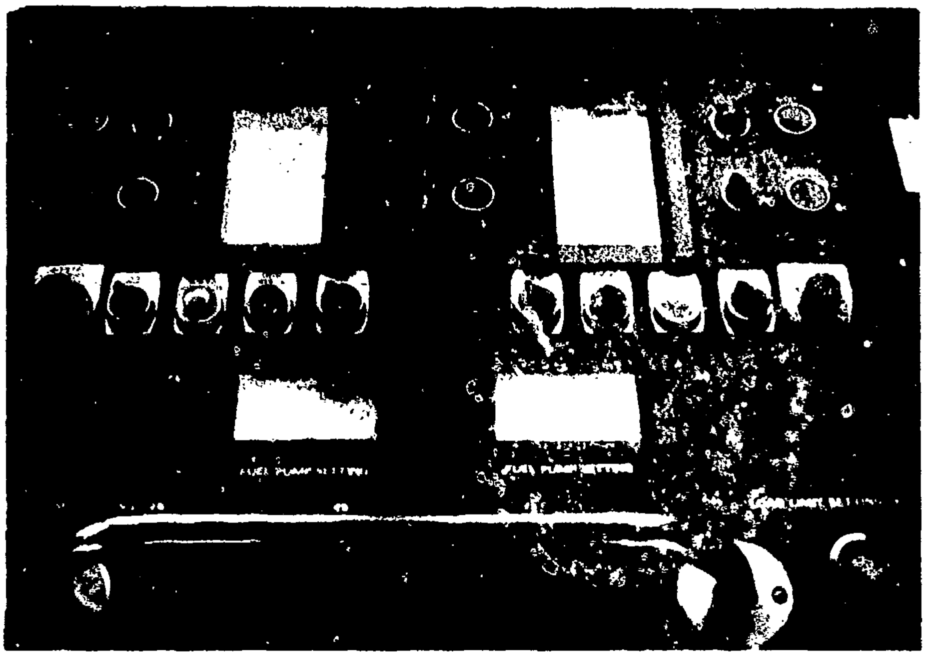
RHS 200 Hullborne - Backing Down



Propulsion Control

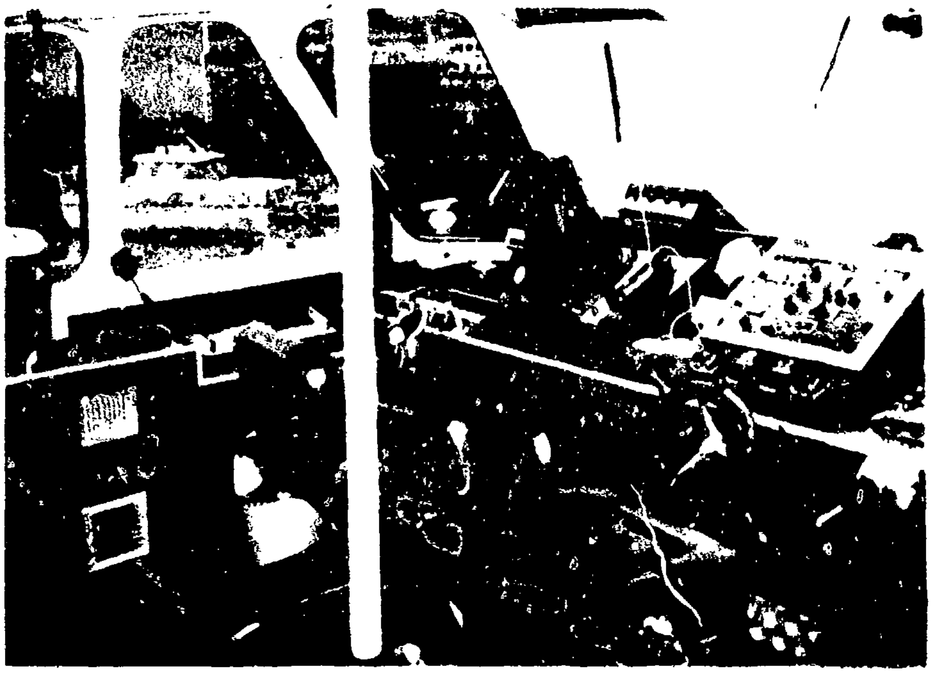


Helm and Seakeeping
Augmentation System

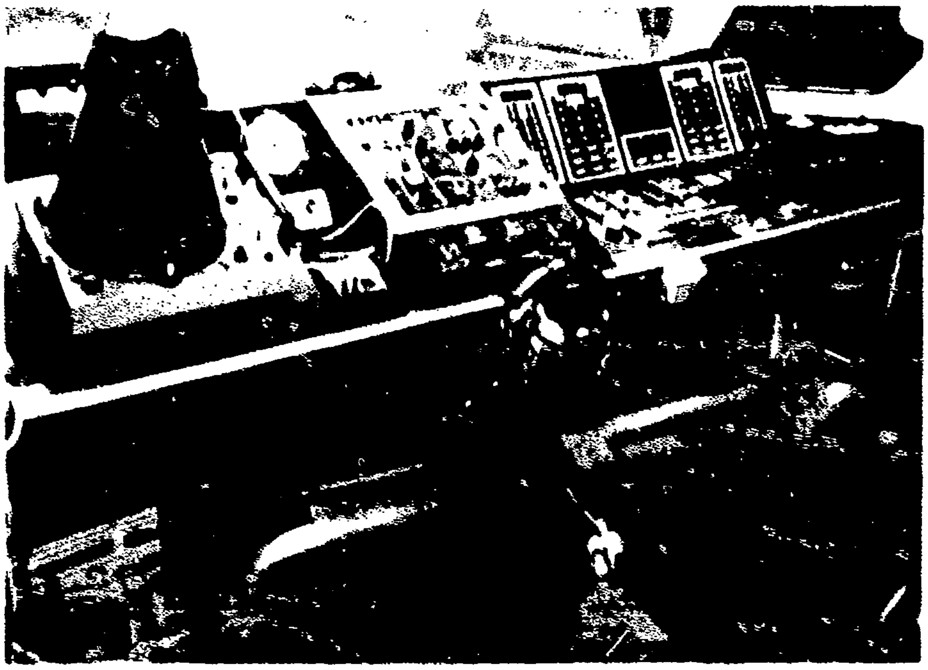


Machinery Monitoring Panel

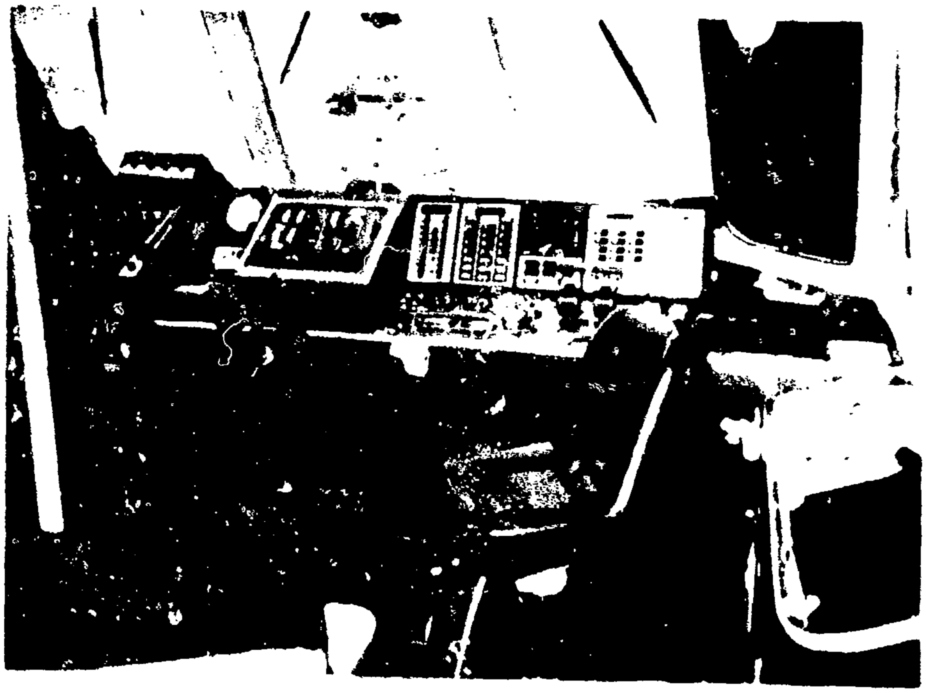
Lighting/Auxiliary Control



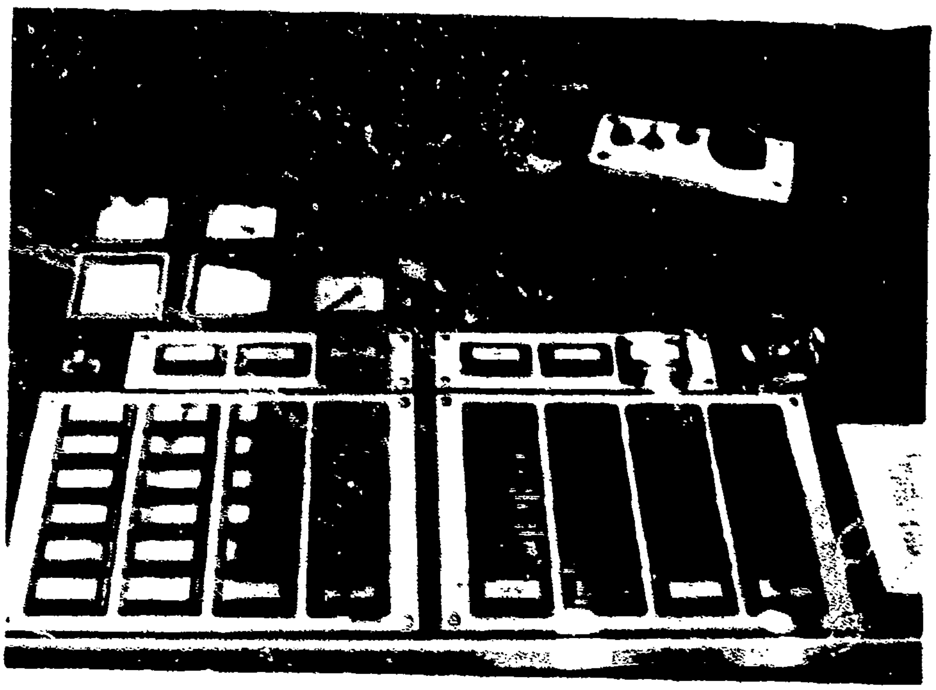
Pilot House Overview - Port Side



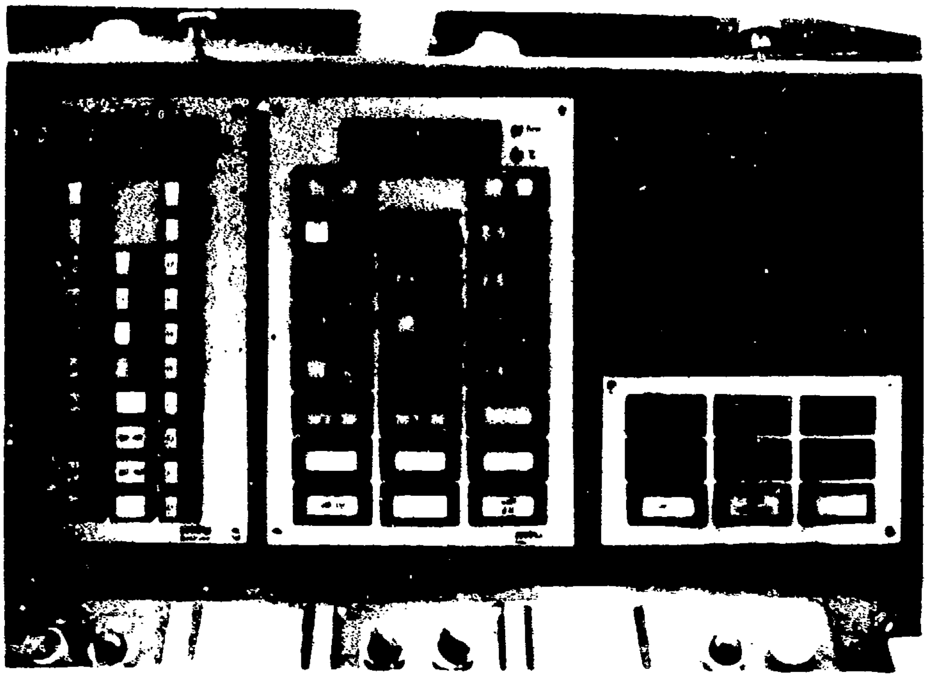
Captain's/Helmsman's Position



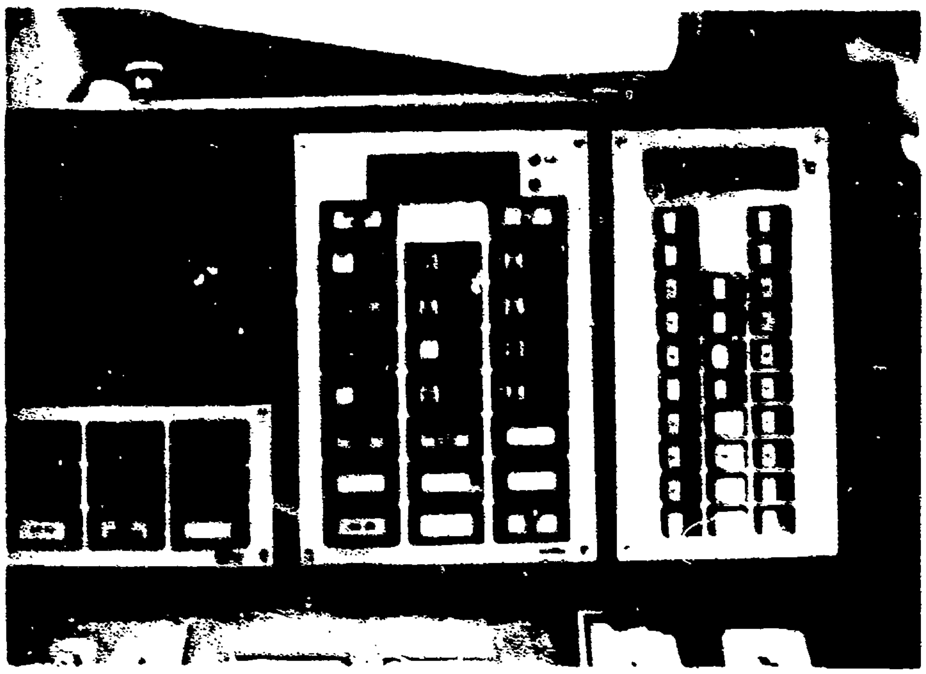
Engineering Control Station



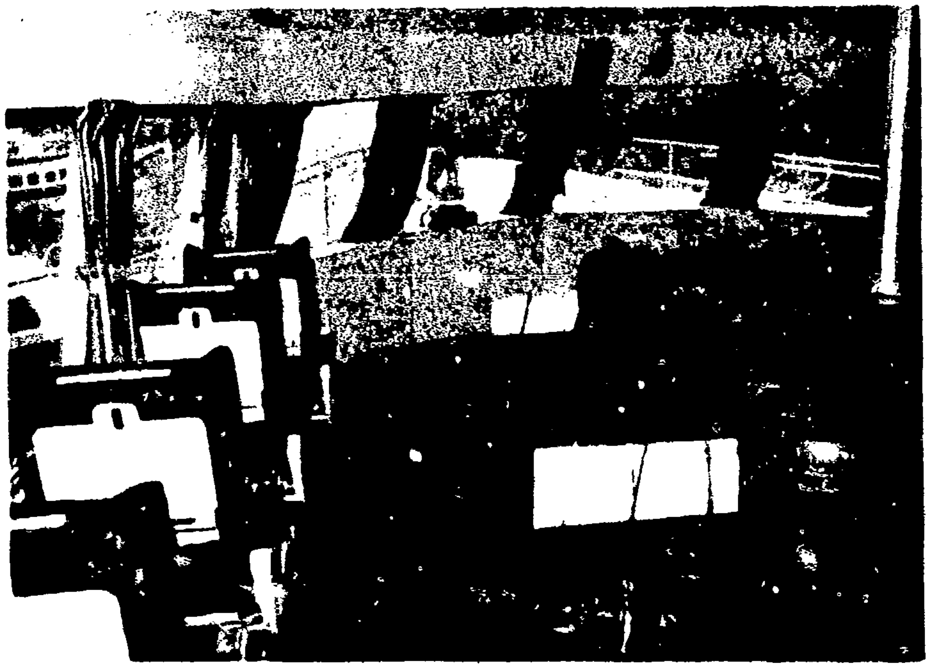
Machinery Monitoring Panel



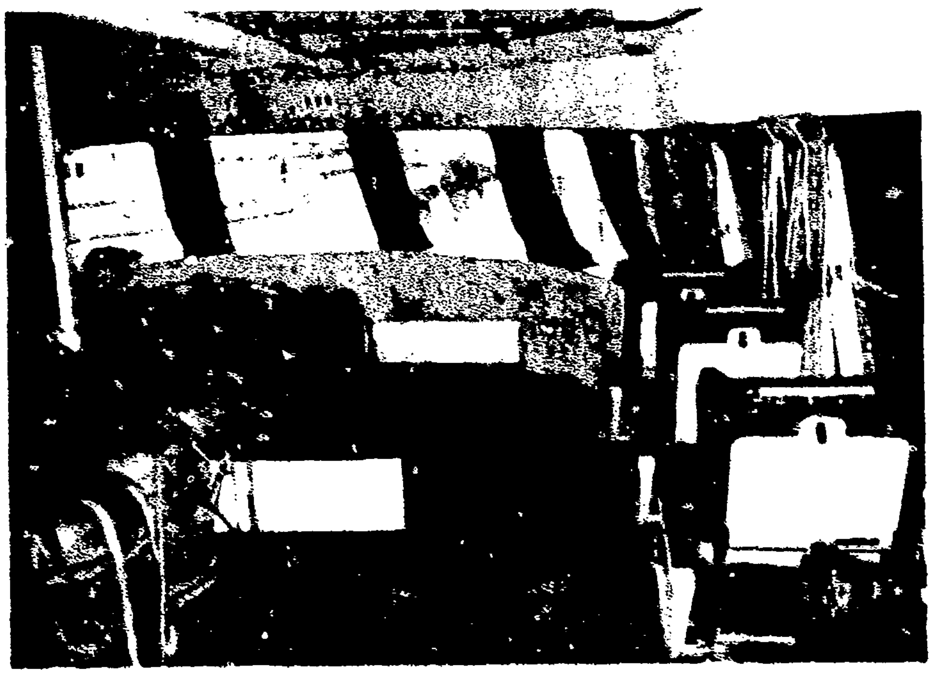
Port Engine Control Panel



Starboard Engine Control Panel



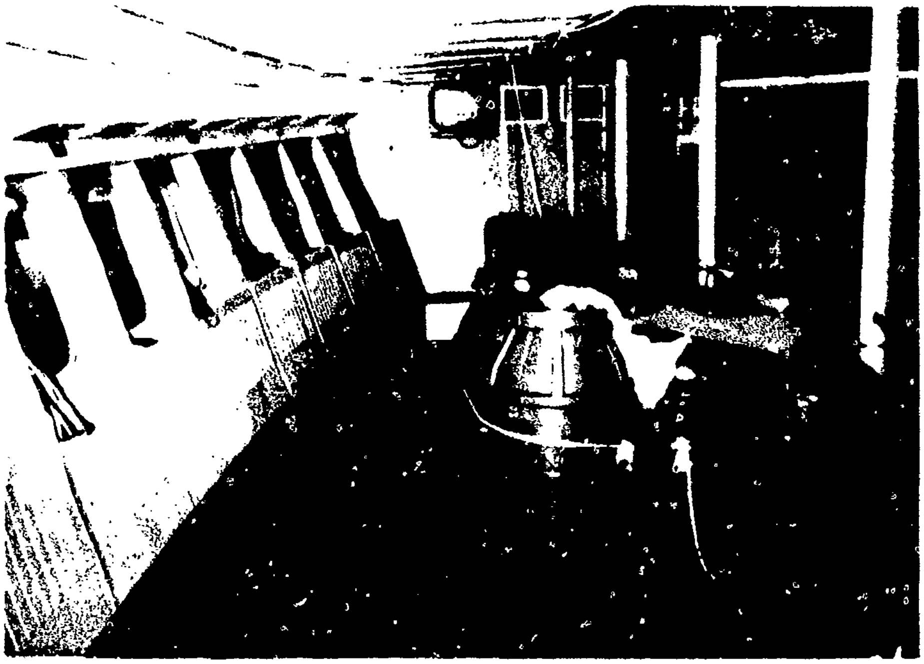
Upper Salon, Port Side - Looking Forward



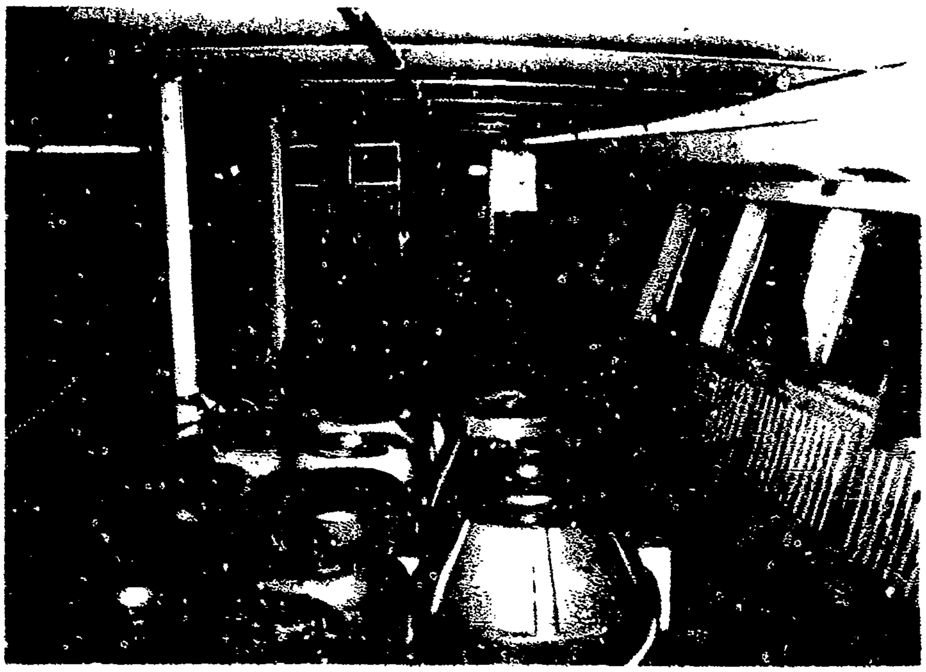
Upper Salon, Starboard Side - Looking Forward

Upper Salon, Starboard Side - Looking Aft

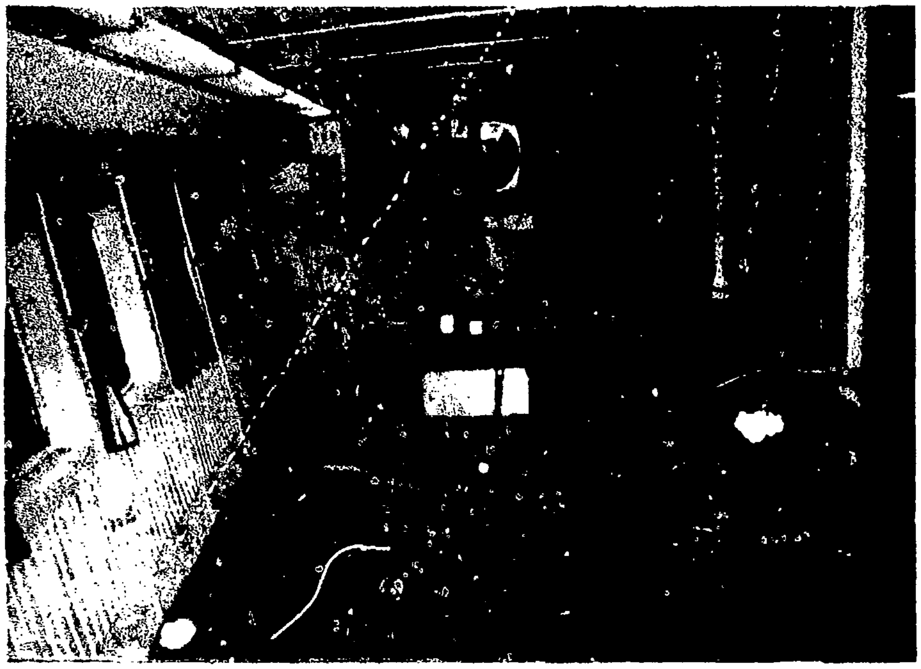
Upper Salon, Port Side - Looking Aft



Lower Forward Salon, Starboard Side
Looking Forward

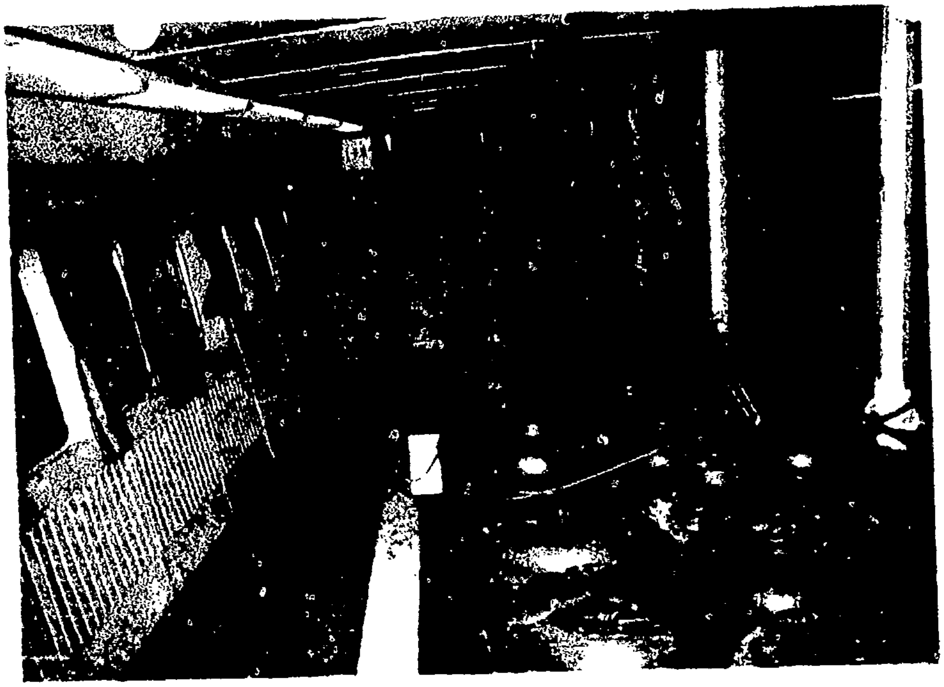


Lower Forward Salon, Port Side
Looking Forward



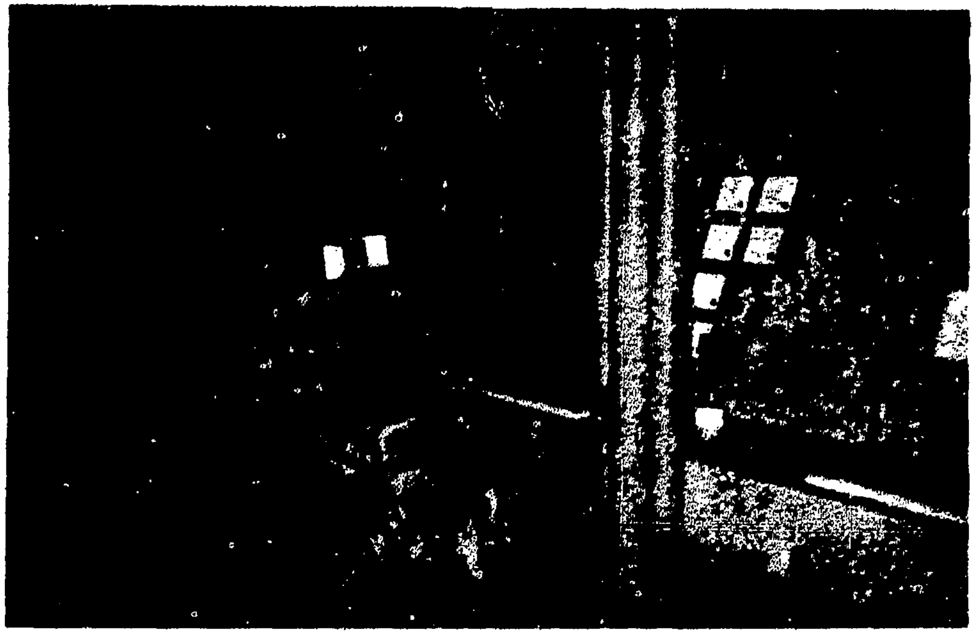
Lower After Salon, Port Side - Looking Forward

Lower After Salon, Starboard Side - Looking Forward

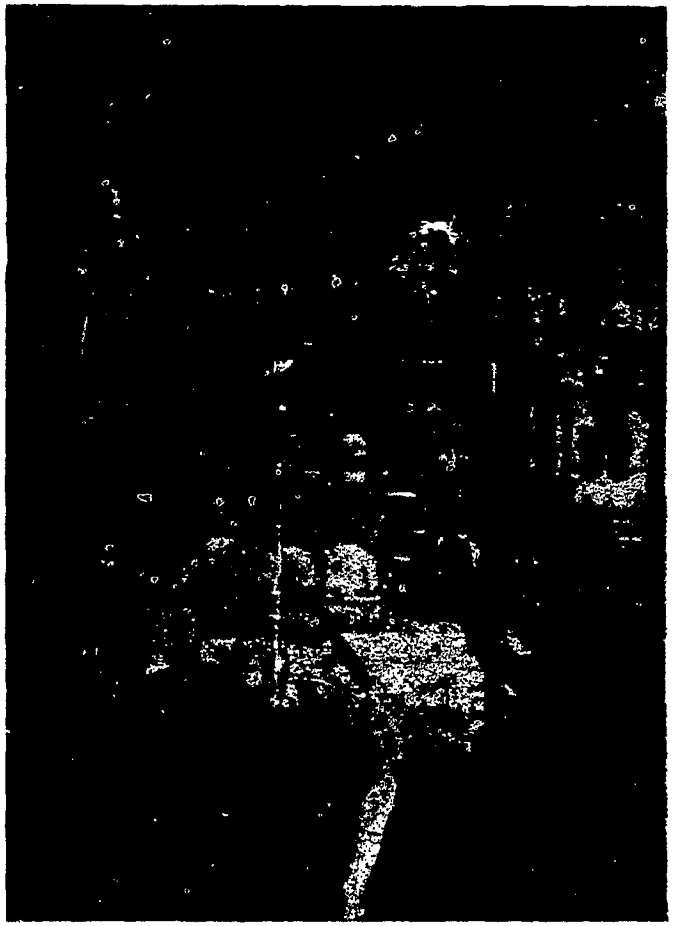


Lower After Salon, Starboard Side - Looking Aft

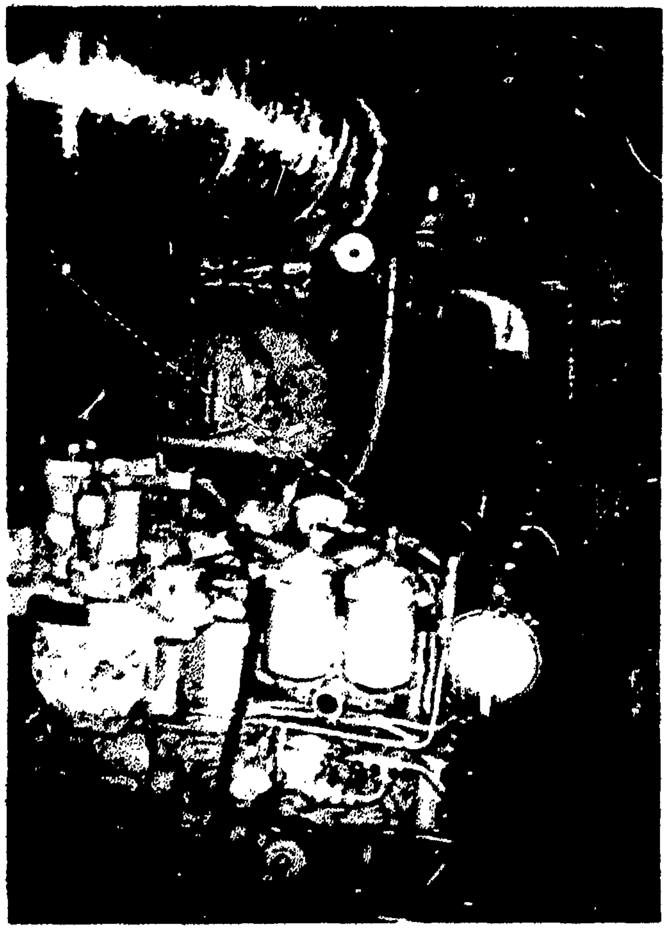
Lower After Salon, Port Side - Looking Aft



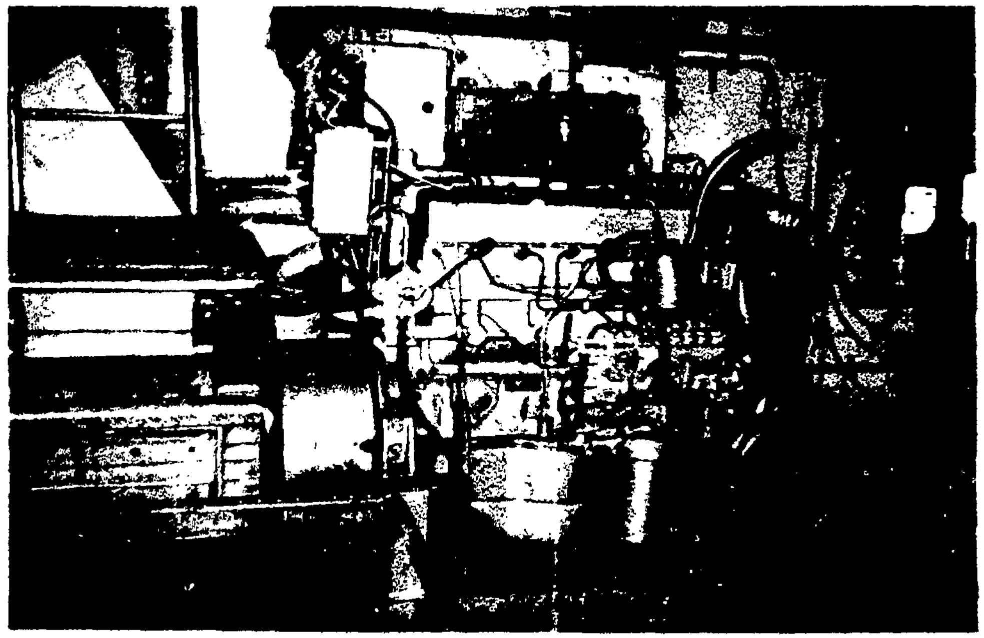
Port Side Of Engine Room
Including Reduction Gear



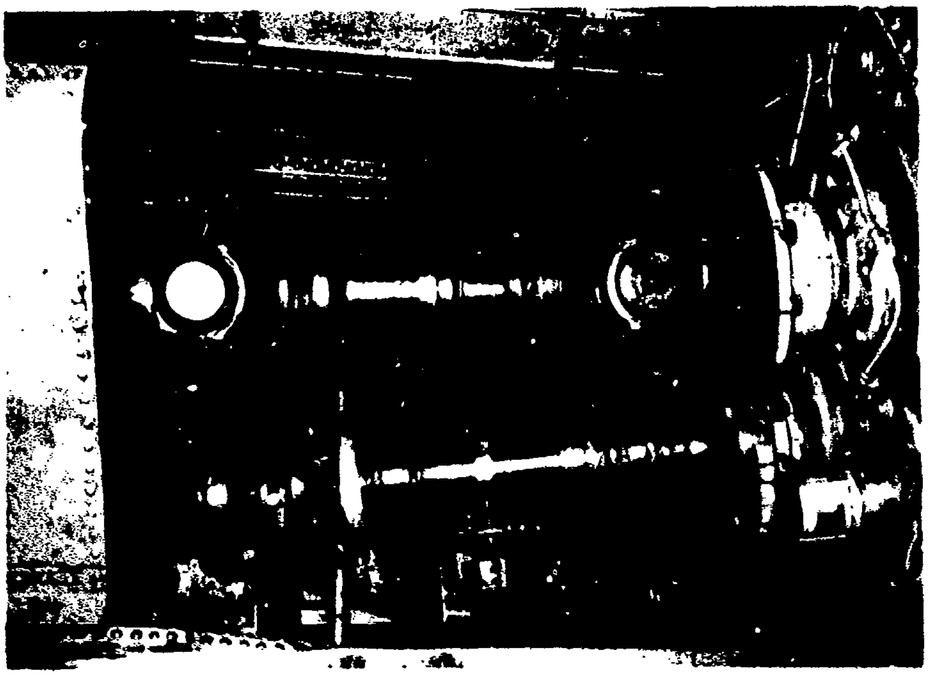
Reduct:on Gear



Main Engine



A/C Generator



Propulsion Shafting

SUMMARY AND CONCLUSIONS

SUMMARY

The RHS 200 is a surface-piercing hydrofoil ship of 123 tons displacement design and built by the Rodriguez Cantiere Navale S.p.A., Messina, Italy as a 254 person capacity passenger ferry. The 117.5 foot ship is powered by two, 2600 horsepower, MTU 16V652-TB81 diesel engines which drive CP propellers installed on angled shafts. The aluminum hulled RHS 200 has an advertised cruising speed of 36 knots and a foilborne range of 200 nautical miles. The ship is fitted with a Seakeeping Augmentation System which uses electro-hydraulic control of flaps installed on submerged elements of the foil systems to minimize ship motions in rough water. The foil systems of the RHS 200 are of alloy steel.

DTNSRDC, at the request of the USCG and the UMTA, agreed to conduct calm and rough water performance and ferry service evaluations of the RHS 200. A trials agenda was written and a portable instrumentation and data acquisition system was assembled by DTNSRDC-HYSTUDET. The instrumentation system was to measure and record data for 36 separate parameters which were either developed within the system, taken from ship's instrumentation, or specially installed by Rodriguez in support of the trials effort. The most important parameters included ship motions and accelerations, control surface positioning, and speed and power measurements.

A trials team was deployed to Messina and the trials were conducted within a six week period beginning 5 April 1982. The calm water trials included definition of ship speed and powering characteristics and takeoff performance at displacements of 110 and 132 ton; spiral, tactical diameter, and zig-zag turning maneuvers; towing performance; and the evaluation of attendant characteristics such as wake profiles, airborne noise surveys, and structural vibration surveys. The rough water trials were largely limited to the conduct of matrix trials where ship powering requirements and responses to five different relative sea headings were measured in State 3 and 5 seas.

The reduction of the calm water trials data was primarily based on computer definition of average values taken over specific time intervals. Additional computer based procedures were used to correct some of the data for instrumentation discrepancies and to integrate data for elapsed time and distance presentations. The rough water speed and power data were reduced parallel to the calm water data. Power spectral density analysis, normal frequency spectral analysis, and manually derived histograms were all used at various stages during the reduction of the rough water motion and acceleration data.

During the calm water characteristic trials it was determined that the ship could achieve foilborne speeds slightly in excess of 36 and 35 knots for the 110 and 132 ton displacements respectively. The ship was power limited at 4400 horsepower in the case of the heavy ship trials and rpm limited at 1460 engine shaft speed in the light ship tests. During foilborne operation the ship is normally trimmed to near optimum attitudes. Hullborne speeds of 15 to 16 knots can be reached at power levels of 2300 to 2500 horsepower. Stable hullborne speeds approaching 19 knots were achieved at 3000 horsepower levels. Single engine hullborne capability to 12 knots was demonstrated.

A heavy ship foilborne range of 275 nautical miles was determined under optimistic procedures which considered 100 percent use of on-board fuel and no allowance for auxiliary consumption. The foilborne best range speed is 30 to 31 knots. A best specific fuel consumption of 0.38 pounds fuel per horsepower-hour was determined using starboard engine measured supply and return fuel flows. The maximum propulsive efficiency defined from the test data was 58 percent. This relatively low value was considered to result from inaccuracies in measured thrust data.

The RHS 200 has a takeoff power margin of over 50 percent. During takeoff the ship is typically clear of the water when a speed of 21 to 22 knots is reached in 15 seconds, and less than 100 yards, from the time and point of throttle advancement. Foilborne operation at 30 knots can be achieved in less than 30 seconds and within a distance of 185 yards. A distance of 30 yards is required to stop the ship using crash reverse procedures from an initial speed of 16 knots. The distance increases to 120 yards with initial operation foilborne at 35 knots.

Compared to a typical hydrofoil, the ship is relatively slow to turn. The maximum turn rate achieved in either the hullborne or the foilborne mode was 3 degrees per second. Directional stability is excellent while in the hullborne mode. Directional stability is reduced, but is always positive, at near zero rudder positions while foilborne. The low turn rates resulted in relatively large tactical diameters. Minimum values were 270 yards while hullborne at 8 knots and 555 yards while foilborne at 28 knots. The application of rudder usually resulted in significant losses in speed. Thirty-five knot foilborne operations could not be maintained during tactical diameter and zig-zag maneuvering tests if rudder commands over 20 degrees were applied at 35 knots. The RHS 200 always responded rapidly to the rudder and steady-state turning conditions were readily achieved. Yaw angle overshoots were very small during the conduct of zig-zag maneuvers. The rudders are completely ineffective while backing down. Differential power provides adequate steering control under these and zero speed of advance conditions.

The towing performance of the RHS 200 was evaluated in bollard pull and in underway tow tests. The ship can develop at least 30,000 pounds of static pull. The tests were limited due to concern over the adequacy of the mooring attachment. An underway tow capability to 16,000 pounds at 11 knots is available and would be adequate to tow a second RHS 200 at this speed.

Tactical response tests could not be performed due to a potential for damaging the engines. As is normal for all diesel power craft the ship should be maintained in a warmed-up status if it is to respond to an emergency condition. Five minute foilborne reaction times could be achieved with advance engine warm-up.

The bow wake of the ship is typically 2 feet in height and has a period of approximately 2.25 seconds in either the hullborne or foilborne mode of operation. The exterior broadside noise levels of the ship are at 85 dB A at 55 yards away. These levels are produced by the unsilenced engine exhausts. The extreme values of broadband interior noise are near the same levels. The interior sound data were obtained under conditions where the sound absorption status of the ship

was severely compromised by removal of seats, etc. This situation would not exist in a normal ship configuration. The propulsion systems are the prime generators of onboard structural vibrations. The most severe vibration levels were recorded on the main deck directly above the propulsion machinery space. The 118 to 114 acceleration dB levels present at frequencies of 40 to 50 Hz could result in some passenger discomfort if exposure was continued beyond 2.5 hours of hullborne operation or 8 hours of foilborne operation.

Rough water matrix trials were conducted in high State 3 seas and low State 5 seas. The matrix test pattern used in the tests allowed evaluation of the response of the ship to head, bow, beam, quartering and following sea conditions. Hullborne trials were only performed in State 3 seas with the SAS secured. The foilborne trials were conducted in both sea conditions with the SAS active and were repeated with the SAS secured. State 3 sea takeoff trials were conducted at each of the given relative sea headings. State 5 sea takeoffs were performed into head seas. The rough water trials data were reviewed on the basis of speed and power characteristics, pitch and roll motions, and the acceleration levels which occurred or were present during the matrix trials.

No significant differences were found in the RHS 200 hullborne speed and power characteristics while operating in either calm water or State 3 seas. There is also little difference in the takeoff capability of the ship operating in calm water, State 3 seas and in State 5 head seas. Foilborne speed and power characteristics in State 3 seas are identical with those found in calm water. The use of the SAS did not have noticeable influence on these results. The effects of the sea and the SAS were both more pronounced in State 5 seas. With SAS control an average increase in power of 11 percent over that required for calm water operation occurred. With the SAS secured the average speed maintained in the tests was reduced and the power required averaged at least 22 percent higher than the calm water requirement. The range reductions which occurred in rough water operation were consistent with the power and speed changes.

Ship motions while on the hull in State 3 seas are very well damped by the foil system. Significant pitch angle excursions averaged 1 degree. Roll data from these tests were adversely effected by the presence of a large low frequency

swell. Disregarding the swell, it was estimated that significant roll angle excursions would also have averaged 1 degree. The SAS was not activated in the hullborne tests because of an expected lack of low speed flap control authority.

While foilborne in State 3 seas the significant pitch angle excursions varied from 0.5 to 1.0 degrees without the SAS and 0.5 to 0.75 degrees with the SAS. In State 5 seas the angle varied from 1.0 to 2.25 degrees with the SAS secured and 0.5 to 1.5 degrees with the SAS active. The sea induced significant roll angles were also of relatively low values. Roll excursions of 1 to 3 degrees occurred in State 3 seas with the SAS secured. These values were reduced to 0.7 to 2 degrees through the use of the SAS. The ship continued to be well behaved in roll even in the higher sea condition. Significant roll excursions of 2 to 3.5 degrees occurred in State 5 seas without the SAS. These values were in the range of 1 to 2 degrees with an active SAS. The most significant fact to be found in these results are the very low pitch and roll excursions which occurred even with the SAS inactive.

The dampening of RHS 200 motions in a seaway may have been at the expense of increased accelerations. In most of the data obtained, the effect of the SAS on accelerations could not be clearly identified as either beneficial or detrimental. The acceleration data are presented and discussed in terms of standard deviations about the mean. A factor of 2.0 should be applied to the given data if estimates of the significant acceleration values are desired. In State 3 seas operation the lateral acceleration values measured at the CG averaged 0.06g. Vertical accelerations at this location and time averaged 0.067g. Both values were increased by approximately 0.01g in State 5 seas. Surge accelerations at the CG averaged 0.03g in State 3 seas and 0.05g in State 5 seas.

The standard deviations in accelerations recorded at the pilothouse were more severe. Average State 3 sea lateral accelerations of 0.09g and vertical accelerations of 0.13g were developed. The lateral accelerations at the pilothouse was not appreciably changed in State 5 seas. The vertical accelerations at this station in State 5 seas varied from .13g to .17g with the SAS active and .13g to .20g with it secured. This is essentially the only case where the SAS had clear impact on the accelerations. The most severe vertical accelerations were recorded in the forward lower cabin where they varied from .15g to .22g in

State 5 seas. The most severe lateral accelerations in State 5 seas were recorded in the aft lower cabin. These standard deviation values averaged 0.12 and were nearly constant with heading of the sea.

During the trials period, a large number of dimensional measurements were taken and observations were made. These permitted evaluation of the RHS 200 in a passenger ferry role for American operation and of the RHS 200 and its M-600 derivative in a United Stated Coast Guard role.

The RHS 200 was soundly constructed. From a review of the drawings, it was felt that the M-600 would also be well constructed. The M-600 was also found to be acceptable under stability and buoyancy criteria likely to be enforced for a vessel of this type and size.

The RHS 200 engineering plant and deck equipment were found to be well arranged for a small ship. In particular, visibility from the pilothouse was excellent.

The struts and foils extend beyond the sides of the ship. This requires special consideration at the pier and when coming alongside. Camels or fenders would be required at the pier.

The reliability and availability of the RHS 200 were found to be excellent. No failures occurred during the test period. The correction of one failure prior to the test period, the installation of test equipment, and planned maintenance were observed. These observations showed that maintainability was clearly considered in the design of the ship and the selection of its components.

The RHS 200 and M-600 were generally capable of supporting USCG missions. However, some modifications to the ship would be required. The communications, navigation and collison avoidance equipment would require upgrading. The habitability on the M-600 would require improvements as well.

The RHS 200 was not designed with wheel-chair users in mind. A number of deficiencies in the area should be corrected.

The RHS 200 falls short of the regulations for passenger vessels of this size. A number of areas would require redesign or waivers from the Coast Guard. Some of these areas include fire protection, firefighting, passenger access and escape, subdivision, lifesaving equipment and electrical engineering.

CONCLUSIONS

The trials conducted in the RHS 200 performance evaluation investigated the operational limits of the ship. The trials were successful and it was determined that the ship performed well in all areas of its design envelope. The following comments are relative to the performance of the ship but may not be necessarily based on numerical data.

The ship was operated on twelve separate voyages during the trials. None of the trials were disrupted or postponed due to any mechanical problem. Once warm-up was completed, departures were quickly accomplished. The voyages varied in length from 2 to 8 hours. At the end of a typical day, the crew would complete normal machinery maintenance and be ready to secure before the trials crew could complete normal end-of-day activities. All individuals involved in the trials were impressed with the physical appearance of the ship; its lines, appointments and arrangements. It was felt that normal housekeeping activity could be easily accomplished.

As a result of the 50 percent takeoff power margin, ship takeoff accelerations were impressive. The speed-power and lift-drag characteristics of the ship are difficult to judge without reference to comparable surface-piercing hydrofoil design information. While higher propulsive efficiencies would be desirable, they are equivalent or superior to other hydrofoil ships. Except during emergency stopping the benefits of the CP propeller were not distinctly evident. Adequate low and reverse speed control with fixed-pitch propellers and reversing gearboxes was demonstrated during a RHS 160 docking exercise. Rodriquez indicated that the relatively low ship turn rates could be improved with increased rudder area. The use of "spade" rudders below the foils may offer a more direct method of improvement.

The rough water ride qualities of the ship were well damped with and without the SAS. Occasional State 5 head sea slams which doused the pilothouse windshield with spray, resulted in motions judged hardly noticeable in the main deck aft cabin. Two members of the trials team were aboard during rough water. Both individuals were comfortable during the State 5 sea tests. The SAS was more

effective in improving ride quality than the data indicated. Neither individual was concerned in regard to the capability of the ship to operate safely in any of the seas encountered.

The RHS 200/M-600 could be designed for use as a U.S. Coast Guard patrol boat. All of the fundamental properties desirable in such a craft are present in the RHS 200.

Although a number of its qualities, such as its performance and reliability and maintainability, make it attractive as a ferry, others do not. If it was to be employed for U.S. domestic passenger service, a number of improvements would be required or desirable. Some of these are fundamental to the ship's design.

ACKNOWLEDGEMENTS

The opinion is held that the surface-piercing hydrofoil ship performance data and other information included in this report is unique within the hydrofoil ship community. This information would not be available without the assistance of many individuals from a number of different agencies. The authors take this opportunity to thank all individuals who participated in this effort, most especially the Management and Personnel of Rodriquez Cantiere Navale, and most particularly the Captain(s) and Crew of the SUPERJUMBO. Special thanks are also extended to Engr. D. Mazzeo of the Rodriquez organization who provided valued technical assistance in all phases of the on-site trials effort. Mr. R. J. Johnston, then of DTNSRDC, acting as overall manager of the program exercised his leadership with usual tact and diplomacy thus ensuring full cooperation of all agencies involved in the effort. The efforts of Messers Robert Krussel and Kevin Gordon of Cross Sound Associates, Seattle, Washington in the development, assembly and calibration of the instrumentation system are deeply appreciated. Mr. Neil Miller of Westinghouse Digital Data Systems, Silverdale, Washington was responsible for programming the data recorder used in the trials and for its completely satisfactory operation throughout the trials period. The authors are very grateful for the effort expended by Mr. W. S. Bond of the Boeing Aerospace Company, Seattle, Washington in meeting the full responsibility for the calibration, installation and operation of the instrumentation system prior to and during the trials. Mr. Bond also provided indispensable support over many long and tedious hours in the post-trial data reduction effort. His level of committment was extraordinary. Mr. Robert Cashmore and Ms. Loraine Hauschild of Art Anderson Associates, Bremerton, Washington have earned an appreciative well done for their work in preparing the graphics used in this report. Ms. Terri Morris and Ms. Cynthia Ponciroli of DTNSRDC-HYSTUDET are sincerely thanked for their assistance in all of the tasks associated with the final preparation of this report. The report was edited by John Meyer and Robert May of the Advanced Hydrofoil Office at DTNSRDC.

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APPENDIX A

SUMMARY OF RHS-200 PASSENGER QUESTIONAIRES - SUMMER 1982
VOLUME I

Passenger questionaires from forty six voyages of the RHS-200 are summarized below. A total of 1797 questionaires organized in four volumes were submitted to the U.S. Coast Guard for evaluation.

ITEM NO.	VOYAGE NO.	DATE	FROM	TO	SEA COND.*	NUMBER OF QUESTIONAIRES
1.	Noleggio	6/1/82	Vulcano	Palermo	0	45
2.	1/A	6/2/82	Palermo	Ustica/Napoli	2	17
3.	2A/R	6/5/82	Palermo	Ustica/Napoli & ret.	0	60
4.	3A/R	6/6/82	Palermo	Ustica/Napoli & ret.	2	74
5.	4A/R	6/7/82	Palermo	Ustica/Napoli & ret.	0	7
6.	5A/R	6/8/82	Palermo	Ustica/Napoli & ret.	0	16
7.	6A/R	6/10/82	Palermo	Ustica/Napoli & ret.	0	43
8.	7A/R	6/11/82	Palermo	Ustica/Napoli & ret.	0	43
9.	8A/R	6/12/82	Palermo	Ustica/Napoli & ret.	5	35
10.	11A/R	6/16/82	Palermo	Ustica/Napoli & ret.	3/4	68
11.	12A/R	6/17/82	Palermo	Ustica/Napoli & ret.	3	8
12.	13A/R	6/18/82	Palermo	Ustica/Napoli & ret.	0	9
13.	14A/R	6/19/82	Palermo	Ustica/Napoli & ret.	3	79

VOLUME II

ITEM NO.	VOYAGE NO.	DATE	FROM	TO	SEA COND.*	NUMBER OF QUESTIONAIRES
14.	15A/R	6/20/82	Palermo	Ustica/Napoli & ret.	0	113
15.	16A/R	6/21/82	Palermo	Ustica/Napoli & ret.	2/3	31
16.	17A/R	6/23/82	Palermo	Ustica/Napoli & ret.	2/3	5
17.	18A/R	6/24/82	Palermo	Ustica/Napoli & ret.	3	43
18.	19A/R	6/25/82	Palermo	Ustica/Napoli & ret.	3/4	12
19.	20A/R	6/26/82	Palermo	Ustica/Napoli & ret.	3/4	116
20.	21A/R	6/27/82	Palermo	Ustica/Napoli & ret.	6	33
21.	22A/R	6/28/82	Palermo	Ustica/Napoli & ret.	6	48
22.	23A/R	6/30/82	Palermo	Ustica/Napoli & ret.	2/3	39
23.	24A/R	7/1/82	Palermo	Ustica/Napoli & ret.	3/4	52

* Beaufort Scale

VOLUME II (Continued)

ITEM NO.	VOYAGE NO.	DATE	FROM	TO	SEA COND.*	NUMBER OF QUESTIONAIRES
25.	26A/R	7/3/82	Palermo	Ustica/Napoli & ret.	0	34
26.	27A/R	7/4/82	Palermo	Ustica/Napoli & ret.	0	41
27.	28A/R	7/5/82	Palermo	Ustica/Napoli & ret.	0	7
24.	46A/R	7/2/82	Palermo	Ustica/Napoli & ret.	2	41
28.	29A/R	7/7/82	Palermo	Ustica/Napoli & ret.	2	28
29.	34A/R	7/12/82	Palermo	Ustica/Napoli & ret.	0	14
30.	35A/R	7/14/82	Palermo	Ustica/Napoli & ret.	0	17
31.	37A/R	7/16/82	Palermo	Ustica/Napoli & ret.	0	8

VOLUME III

ITEM NO.	VOYAGE NO.	DATE	FROM	TO	SEA COND.*	NUMBER OF QUESTIONAIRES
32.	40A/R	7/19/82	Palermo	Ustica/Napoli & ret.	3	38
33.	41A/R	7/21/82	Palermo	Ustica/Napoli & ret.	0	5
34.	42A/R	7/22/82	Palermo	Ustica/Napoli & ret.	0	23
35.	43A/R	7/23/82	Palermo	Ustica/Napoli & ret.	3/4	115
36.	44A/R	7/24/82	Palermo	Ustica/Napoli & ret.	5	19
37.	45A/R	7/25/82	Palermo	Ustica/Napoli & ret.	4/5	10
38.	46A/R	7/26/82	Palermo	Ustica/Napoli & ret.	5/6	29
39.	47A/R	7/30/82	Palermo	Ustica/Napoli & ret.	0	96
40.	48A/R	7/31/82	Palermo	Ustica/Napoli & ret.	2	42
41.	53A/R	8/6/82	Palermo	Ustica/Napoli & ret.	2/3	60

VOLUME IV

ITEM NO.	VOYAGE NO.	DATE	FROM	TO	SEA COND.*	NUMBER OF QUESTIONAIRES
42.	63A/R	8/18/82	Palermo	Ustica/Napoli & ret.	2/3	13
43.	70A/R	8/26/82	Palermo	Ustica/Napoli & ret.	2/3	87
44.	71A/R	8/27/82	Palermo	Ustica/Napoli & ret.	2/3	31
45.	83A/R	9/10/82	Palermo	Ustica/Napoli & ret.	2	24
46.	93A/R	9/22/82	Palermo	Ustica/Napoli & ret.	4/5	19